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<div style="text-align:center">CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.</div>

4

CONTENTS

A CHAPTER IN THE HISTORY OF ZOOLOGICAL NOMENCLATURE

BY
LEONHARD STEJNEGER

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It seems unavoidable that questions, which during the progress of science have caused controversies and then become settled by compromise or otherwise, should reappear from time to time and then give rise to renewed agitation and a restatement of the old arguments. Sometimes such resurrection of old issues is due to the growth or development of science itself, but often it arises from lack of first-hand knowledge of the previous history of the question and its disposal. Much energy and time have been wasted in thus threshing over old straws, simply because there was not at hand a comprehensive historical account of the processes which led up to the final settlement—or rather the settlement which it was intended should be final.

It is hoped that the following recount of the steps by which agreement was secured with regard to certain phases of the International Zoological Code of Nomenclature may prevent the recrudescence of an old controversy which it took twenty years to settle when it was up the last time. This is the more to be desired as the result then achieved has stood the test of twenty years' experience.

I. SPECIFIC NAMES BEFORE 1758

Before proceeding, it may be well to clear up one common misconception, namely, that the zoological nomenclature, the origin of which is usually credited to Linnaeus, did appear suddenly as something entirely new.

The genus concept, such as we recognize it even today, as well as the generic name, such as we employ it today, are due to Tournefort and other predecessors of Linnaeus. As an almost necessary corollary, so were the species concept and the species designation. But Linnaeus was the first to give them *universal* application by his " methodus nova," by which he outlined and defined logically a rigid set of named categories, into which he fitted all the objects of nature known to him.

Linnaeus' Systema Naturae was not only intended to be an exposition of systematic zoology, but it was also to be what nowadays we might call a check-list of names. This is perfectly plain from an inspection of the very first edition of 1735. Even at that early time he stressed the point that the method of natural history consists in " Divisio *ac* Denominatio." It has been said that in the first and the second editions (1740) he only treated of the genera. That is only a partial truth. The title proclaims it to be a systematic presentation of the three Kingdoms of Nature by " classes, ordines, genera & species," and the contents do not belie the title page. It is true that only the genera are characterized, but the species are named, and what is more, mostly binominally. However, they are not diagnosed, so that they are what we now understand by " *nomina nuda,*" but they are *nomina,* nevertheless.

But whether we accept the contention of those who prefer to call the plurinominal designations of the later editions " differentiae " and not " nomina " is of no moment, as this argumentation is merely a juggle with words. The fact is that before 1758 Linnaeus himself, when he wanted to refer to a species *by name,* say for instance the species of the Golden Pheasant, would have to write *Phasianus crista flava, pectore coccineo* (Syst. Nat., Ed. 6, 1748, p. 28) and there can scarcely be any doubt that this is the *" Nomen selectum; genericum & specificum Authoris cujusdam (si quod tale) vel proprium "* to which he refers (*op. cit.,* p. 222). Who would have the hardihood to deny that *Dasypus cingulis novem* or *Dasypus cingulis septem* were *names* given them by Linnaeus in 1748 just as much as the names *Dasypus novemcinctus* and *D. septemcinctus* bestowed upon them in 1758? Moreover, such designations as *Lernea lepus marinus, Aphrodita mus marinus, Medusa urtica astrophyta* (*op. cit.*) can scarcely be referred to as " differentiae " if by that term something else is meant than by " nomina." Finally, the 1748 edition is, to a very great extent, *binominal,* though the principle is not carried through consistently until the 1758 edition. To show this, it is only necessary to reprint, out of many examples, his list of the species of the genus *Parus* of 1748 (p. 32).

83. PARUS. Rostrum subulatum.

Linguae apex truncatus, terminatus setis quattuor.

1. Parus major. *Fn.* [Fauna Svecica, 1746] 238.
2. Parus cristatus. *Fn.* 239.
3. Parus caeruleus. *Fn.* 240.
4. Parus ater. *Fn.* 241.
5. Parus palustris. *Fn.* 242.
6. Parus caudatus. *Fn.* 243.

Compare this with the tenth edition, 1758, pp. 189-190, where we have the following:

100. PARUS. *Rostrum* integerrimum.

          Lingua truncata, setis terminata.

The accepted "binominal" names of the above six species are enumerated as follows:

    1. Cristatus.

    2. Major.

    4. Caeruleus.

    5. Ater.

    6. Palustris.

    7. Caudatus.

Surely here is no difference; nor is it likely that anybody may argue that this binominalism is incidental or accidental.

While thus 1758 does not in itself mark a sudden revelation in zoological nomenclature, this year, after the long and painful experimentation by the zoologists with another year (1766), has come out victorious as a starting point chiefly on account of practical considerations.

The fact is that while Linnaeus was a master methodologist and a great systematic naturalist, there were among his contemporaries men who in their more limited fields possessed a wider and deeper insight than Linnaeus himself. They were so closely synchronous with him that he could not benefit by their work and they had hardly time, if they had the inclination, to adapt their own writing to his. Nevertheless, their influence upon their special branches has been so profound, that their successors a hundred years after have insisted on preserving at least so much of the zoological nomenclature originating with them as could be reconciled with, or rather as coincided with, that of the great Swede. By selecting 1758 as a starting point, it became possible to recognize all mononominal generic names originating after that date, although the species designations might be inapplicable.

It has been asserted repeatedly that by admitting the genera of binarists, who after 1758 were not also binominalists, we are guilty of inconsistency by recognizing authors who were not "playing the Linnaean game." But, when did Linnaeus himself begin to play the game? Surely not in 1758. He began it in 1735 with the "Systema Naturae sive regna tria naturae systematice proposita per classes, ordines, genera, & species" as the title page has it, and as it was repeated with slight verbal changes in each of the following editions (2d, 6th and 10th) brought out by Linnaeus himself. Gradually the

game developed. The sixth edition (1748), as already shown, contained a large number of binominal specific names—not incidentally or accidentally, but intentionally so—and in 1753 only five years after the sixth edition, Linnaeus carried out the binominal system consistently as far as the plants were concerned. Five years later (10th ed.) he carried it out equally consistently for the animals. For practical reasons given above, the recent codes of zoological nomenclature decided to start with 1758, and not because this edition initiated a new " game "; it only inaugurated its consistent general application. If then Linnaeus himself did not play a new game in 1758 and after, surely those who had followed him thus far still played the same game, as I shall demonstrate later on (Brisson, p. 18).

It was also for practical reasons that generic denominations dating from before 1758 have been excluded much against the protest of the French zoologists.

II. BINARY AND BINOMINAL

Fortunately the word *binominal*[1] presents no serious difficulty. Except in a few isolated cases of carelessness, it is used by all authors to designate a system of nomenclature in which both the genus designation and the species designation each consist of a single word.

Much mischief has been caused by the introduction and common synonymizing of the term *binomial* with the above. Many authors have even gone so far as to intimate that it is an " abbreviation " for binominal. The two words are from different roots and ought to mean different things, but it matters little, for *binomial* has been commonly used indiscriminatingly for binominal. Properly it ought to mean the same as binary of Opinion 20 of the International Commission, and has been so used by some authors.

Binary, however, is the word about which much controversy has been raging. Etymological dictionaries have been consulted as to its origin and meaning; zoological literature has been searched so as to trace its application; its use by individual writers has been analyzed in order to interpret its hidden meaning. And everybody has interpreted it to suit himself. The Latin word *binarius,* meaning simply " that which consists of two," lends itself admirably to such interpretation. Some argued that binary nomenclature referred to names consisting of two *terms,* others that it referred to names consisting of two *words.* To some it was synonymous with *binomial,* to others with *binominal,* and as most authors confused binomial and binominal,

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[1] The Latin adjective *binominis*=cui geminum est nomen, ut Numa Pompilius, Tullus Hostilius.

naturally they also confused binary and binominal. And there is no denying the fact that the three words have been used most loosely and almost indiscriminately by nearly everybody. With one notable exception: the International Zoological Code of Nomenclature.

We are not interpreting the meaning of this ambiguous word as it has been used by this or that author, by this or that code. We are not investigating who used it first in this or that connection; nor who defined it first in this or that way. The only question before us is: What is its meaning in the present International Code and how did it come to have that meaning?

III. THE INTERNATIONAL CODE

During the seventies and the beginning of the eighties of the last century the zoological nomenclature was on the verge of chaos due to the fact that the old Stricklandian Code because of its inherent weaknesses, its many exceptions, and inconsistencies, its vagueness, and the freedom it offered to individual interpretation, was celebrated more in the breach than in the observance. Practically every taxonomist followed his own rules, or rather his own preferences or taste. Great changes in long familiar names were the order of the day due to the discovery of overlooked early publications or to the substitution of the 1758 edition of Linnaeus' Systema Naturae for the 1766 edition, or to the fact that generic names in zoology had been rejected or retained, as the case might be, because of, or in spite of, their having also been applied to plant genera, etc., etc. At the same time the question of naming subspecies by applying a third term to the specific name, thus introducing a trinominal nomenclature, was becoming acute and pressed for a solution. The result was that two lists of the same group of animals from the same region, but by different authors, might be so unlike as to perplex even the most expert professional.

The Committee on Zoological Nomenclature of the American Association for the Advancement of Science, taking cognizance of this condition, published in 1877 an exhaustive report submitted at its request by Dr. W. H. Dall (Proc. Amer. Assoc. Adv. Sci., Nashville, 1877, pp. 7-56), in which the whole question was thoroughly discussed. It embodied the views of a large number of American taxonomists. This report is of great importance as setting forth the various opinions and arguments, but it did not lead to definite results with regard to some of the most debated points, such as a single definite date for starting the zoological nomenclature, though it made the recommendation that no specific names are to be recognized if

proposed before 1758. With regard to genera the idea seems to have been that some " epoch-making work," from which the nomenclature is to start, may be determined for each class or greater group by the students specializing in the same. It is incidentally pointed out that G. R. Gray, in 1841, " adopts the first edition of the Systema (1735) as the epoch-maker for ornithological genera. For specific names he does not go behind the tenth edition." It should be noted that the recommendations of the report aim at bringing about as near an approach between the zoological and the botanical codes of nomenclature as possible without making them identical.

The ornithologists have always been active in nomenclatorial matters so that it was quite natural that at the founding of the American Ornithologists' Union in 1883, one of its first acts was to create a committee to which was referred " the question of a Revision of the Classification and Nomenclature of the Birds of North America." The committee soon realized that no such revision could be undertaken without a discussion of the general principles of zoological nomenclature, a discussion which resulted in the formation of a Code of Rules for the guidance of the committee. " These rules were considered in their bearing upon zoology at large as well as upon ornithology alone, it being obvious that sound principles of nomenclature should be susceptible of general application." In publishing the Code (The Code of Nomenclature . . . . adopted by the American Ornithologists' Union. New York, 1886) the hope was expressed " that the new Code will find favor, not only with ornithologists generally." This hope was speedily realized as numerous American zoologists, specialists in all classes of the animal kingdom, publicly announced their adherence to the A. O. U. Code, as it came to be known.

While ostensibly based upon the Stricklandian rules, nevertheless the new Code marked a decided departure in zoological nomenclature based as it was upon the principle of an inflexible and exceptionless law of priority, and framed with the express purpose of allowing the least possible play for individual preferences and prejudices. Moreover, it broke definitely with the old " binomial " nomenclature consisting in the application of " two names, one of which expresses the specific distinctness of the organism from all others, the other its superspecific indistinctness from, or generic identity with, certain other organisms, actual or implied ; the former name being the specific, the latter the generic designation ; the two together constituting the technical name of any specifically distinct organism." The A. O. U. Code only regards " the binomial system as a phase of zoological nomenclature." The " trinomial system " is another phase

of zoological nomenclature. The code furthermore provides (canon 12) that "the law of priority begins to be operative at the beginning of zoological nomenclature" and (canon 13) "zoological nomenclature begins at 1758, the date of the 10th edition of the 'Systema Naturae' of Linnaeus." Note well: zoological nomenclature, not binomial nomenclature, nor Linnaean nomenclature! Note also the following reasons given by the committee for dissenting from previous codes in rejecting 1766 as a starting point (p. 36) : "This date [1758] admits to recognition the works of Artedi, Scopoli, Clerck, Pallas, Brünnich, Brisson, in favor of the first-named two of whom, and of the last-named one, the B[ritish] A[ssociation] Committee have had to make special exceptions." In a footnote the Article 2 of the original B. A. Code (1842) is quoted, which admitted the genera of Brisson : "But Brisson still adhered to the old mode of designating species by a sentence instead of a word, and therefore while we retain his defined genera we do not extend the same indulgence to the titles of his species, even when the latter are accidentally binomial in form." The argument winds up as follows (p. 38) : "It seems best that the origin of generic names in zoology should date (as said above) only from 1758 [and not from Tournefort 1700 or Linnaeus 1735] ; that names adopted from earlier authors by Linnaeus date only from their adoption by Linnaeus ; and that in other cases pre-Linnaean names shall date from their introduction by subsequent authors after 1758." It is thus plain that the A. O. U. Code admits all truly generic names proposed after 1758 whether the author is a binominalist or not. The generic names of Gronovius, 1763, are consequently admissible under that code. It may be further noted that in Dall's codification of 1877 and the A. O. U. Code of 1885, only the word *binomial* is used and nowhere the word *binary*.

In the meantime the zoologists on the continent of Europe had also begun to agitate the question of more modern rules of nomenclature. Again it was an ornithologist who first stirred up the question. In 1872 Carl J. Sundevall, the eminent Swedish zoologist, published a book on the natural system of the birds, and in the introduction which was written both in Swedish and French he has a chapter entitled "Remarques sur les noms systematiques" (Methodi Naturalis Avium Disponendarum Tentamen, Stockholm, 1872, pp. lix-lxix). As far as species names are concerned, he was an early and consistent defender of 1758 as a starting point. He wrote (p. lxii) : "C'est de ces dates [1758 in zoology and 1751 in botany] que commencent les noms spéciaux ; mais les noms génériques sont plus anciens. Dans la botanique, ils furent introduits comme principe général par Tourne-

fort en 1694; dans la zoologie ils commencent proprement avec la première édition du *Systema Naturae* de Linné, de 1735, qui est le premier ouvrage ou les genres font partie essentielle du système dans la zoologie, et ils y sont exposée à travers tout le règne animal." This principle, which was none other than that first introduced by the equally eminent English ornithologist, G. R. Gray, in the second edition of his Genera of Birds (1841), the year before the issue of the B. A. Code, namely, one starting point for the names of genera and another for those of species, was rather universally accepted by those who clamored for a revision of the Stricklandian Code. But even among those who favored starting the binominal nomenclature from 1766, the principle was recognized that the status of an author's generic names is not influenced by his adherence to the mononomial (univocal) species designation, as shown by the following quotation from an article by Alfred Newton, one of the stanchest defenders of the binominal system and a member of the revision committee: " His [Brisson's] genera are brought in [into the revised Stricklandian Code of 1865] by a special enactment; but once admitted, they are exactly on the same footing, to stand or fall, as those of anybody else. His specific names, we know, are rejected, but that is simply because he did not adhere to the binomial system of nomenclature which we adopt, and very rightly they are rejected. Had his book been published a few years later, or had the [B. A.] Code enacted that the 10th edition of the ' Systema ' should be the point of departure, there would have been no need to treat him exceptionally as regards his genera." (Ibis (3), vol. 6, 1876, p. 103.)

In France the whole question was reopened in 1879 curiously enough not by the zoologists but by the First International Geological Congress in Paris. A Committee was appointed to formulate " Règles à suivre pour établir la nomenclature des espèces." The members of the paleontological section residing in Paris (Cotteau, Douvillé, Gaudoy, Gosselet, Pomel, and de Saporta) consequently submitted to the second International Geological Congress in Boulogne, 1881, a uniform code for zoology and botany, " prenant pour point de départ le code Strickland," under the title " Règles proposées par le Comité de la Nomenclature paléontologique " (Congrès Géologique International, Compte Rendu de la 2ᵐᵉ Session, Boulogne, 1881, pp. 594-595), consisting of only 11 brief articles, but accompanied by a " Rapport " by Douvillé. The principle accepted is clearly expressed in article 1, which reads as follows : " La nomenclature exclusivement adoptée est la nomenclature binominale, dans laquelle chaque individu est désigné par un nom de genre et par un nom d'es-

pèce" and by article 4a: "Il n'y a pas lieu de fixer dans le temps une limite à la loi de priorité; toute dénomination générique ou spécifique conforme aux règles de la nomenclature binominale devra être adoptée, même si elle est antérieure à Linné." In his "rapport" Douvillé elaborates this principle further by referring to Tournefort who in 1700 "répartit l'ensemble du règne végétal en un certain nombre de *genres* comprenant chacun une série d'*espèces*, caractérisées par leur *différences*" (p. 596).

Stirred by the action of the geologists the Zoological Society of France in the meantime (January 11, 1881) decided not to stand aside as a spectator but to take an active part in the discussion. A commission, consisting of Blanchard, Chaper, Jousseaume, Jullien, Künckel d'Herculais, Lataste, and Simon, was appointed charged with preparing "un corps de règles applicables à la nomenclature des êtres organisés"—consequently covering the same field as the paleontological committee. The commission promptly submitted during the same year a code of "Règles," almost as brief as that of the paleontologists, consisting as it did of only 17 articles, and accompanied by a "Rapport" by Mr. Chaper. It is first to be noted that the zoologists follow the paleontologist in accepting Tournefort as father of the system of generic-specific nomenclature, and consequently in not incorporating in the code a definite date as a starting point for the generic and the specific denominations, both affirming in the identical language that "le nom attribué à chaque genre et à chaque espèce est celui sous lequel ils ont été le plus anciennement désignés" (Paleont. Code, art. 3; Zool. Code, art. 11). Altogether, the two codes are based essentially on the same principles, embodied in the same language, and but slightly altered in the sequence of their articles. Thus articles 1 and 2 of the Paleontological Code correspond to articles 1-7 of the zoologists' code; 8, 9 and 10 of the former are identical with 8 and 9 of the latter. Article 10 of the zoological code is additional and refers to the names of families. P. C. articles 3-5 correspond to the Z. C. art. 11, and P. C. 5 has become Z. C. 12 and 13; 6 has become 14; and 7 embraces 15 and 16. Article 17 of the zoologists' code is additional and provides only for the rejection of a later name having in Latin a pronunciation so little different from the earlier one that confusion might arise.

But while thus there is general agreement both in principle and verbal expression, there is a significant amplification of one phrase in the zoological code which merits special consideration.

Article 1 of the Paleontological Code began as follows: "La nomenclature exclusivement adoptée est la nomenclature *binomi-*

nale," and article 4*a* provides: "toute dénomination générique ou spécifique conforme aux règles de la nomenclature *binominale* devra être adopté, même si elle est antérieure à Linné." The zoologists, however, at once realized the inadequacy of this "definition de la nomenclature" well knowing (as did the paleontologists of course) that there was no binominal nomenclature before Linnaeus. They felt the incongruity of calling the system of Tournefort and of Linnaeus, before the introduction of the univocal *nomen trivialis, binomiNal,* and they consequently set about to rectify this clumsy and ambiguous expression, and in the code submitted by them, the first paragraph of article 1 took this form: "La nomenclature adoptée pour les êtres organisés est *binaire* ET *binominale."* As a consequence Art. 11*b* which took the place of 4*a*, quoted above, came to read as follows: "Le nom attribué à chaque Genre et à chaque Espèce ne peut être autre que celui sous lequel ils ont été le plus anciennement désignés, à la condition: que l'auteur ait effectivement entendu appliquer les règles de la nomenclature *binaire."* Thus the ludicrous reference of the paleontologists to a binominal nomenclature before Linnaeus was gotten rid of.

We are here, for the first time in *this* chapter of the history of zoological nomenclature, introduced to the term "nomenclature binaire," which has since been translated into English as "binary nomenclature," for the definition of which the English dictionaries have been so inconsequently consulted! While there is no explanation of the terms in the accompanying "Rapports," probably for the reason that the framers of the code of the Zoological Society of France found it so obvious that no further definition seemed necessary, there can, of course, be no doubt as to the meaning, viz., that generic names by binarians, even if proposed before the general introduction of the binominal nomenclature, should not be rejected, a principle to which the French, both zoologists and paleontologists, were positively committed.

The Zoological Society of France did not rest with the adoption of this code, but after having taken the initiative in calling the first International Zoological Congress at Paris in 1889, a more detailed code based on the principles of the one already adopted by the society and employing the identical phraseology was introduced, accompanied by a "Rapport" by Dr. R. Blanchard. These "Règles" were further elaborated and commented on at the second meeting at Moscow, 1892, when the first code of the International Zoological Congress, consisting of 63 articles, was there adopted. The articles discussed above have now (1892) the following phraseology:

"Art. I. La nomenclature adoptée pour les êtres organisée est binaire et binominale. . . . .

"Art. 44. Le nom attribué à chaque genre et à chaque espèce ne peut être que celui sous lequel ils ont été le plus anciennement désignés, à la condition : . . . .

"b. Que l'auteur ait effectivement entendu appliquer les règles de la nomenclature binaire.

"Art. 45. La dixième édition du *Systema naturae* (1758) est le point de depart de la nomenclature zoologique. L'année 1758 est donc la date à laquelle les zoologistes doivent demonter pour rechercher les noms génériques ou spécifiques les plus anciens, pourvu qu'ils soient conformes aux règles fondamentales de la nomenclature."

We see consequently *that the International Zoological Congress* repudiated the idea of going back for the generic names beyond 1758 and definitely and unequivocally *committed itself to the acceptance of each generic and each specific designation dating from 1758 and after, thus getting into complete accord with the provisions of the A. O. U. Code.* On this point, therefore, the French and the American zoologists were fully agreed.

Between the first and the second international zoological congresses (1889 and 1892) the Second International *Ornithological* Congress, meeting at Budapest, 1891, also took up the matter of zoological nomenclature, on the initiative of an " Entwurf von Regeln für die zoologische Nomenclatur," originating in Berlin and reported on by Dr. Anton Reichenow. Recognizing that the A. O. U. Code (1886) was " wohl der vollständigste und am schärfsten durchdachte Entwurf von Regeln für die zoologische Nomenclatur, welcher bis jetzt veröffentlicht worden ist," and noting that because of its " vorzüglichen Eigenschaften " most American zoologists had given it their approval, the German " Entwurf " proposed to adhere as closely to it as possible. Reichenow's proposal, with only a few verbal changes, was adopted by the International Ornithological Congress under the title " Regeln für die zoologische Nomenclatur " (Zweiter Internationaler Ornithologischer Congress, Budapest, 1891. Hauptbericht. I, Officieller Teil, pp. 183-190). The special part, which consists of 14 articles, contains the matter in which we are at present interested. Art. 5 reads as follows : " 5. Die allgemeine Giltigkeit des Prioritätsgesetzes beginnt mit der X. Ausgabe von Linné's Systema Naturae (1758). Erläuterung : Das Jahr 1758 gilt als Anfangszeit des Prioritätsgesetzes ebensowohl für Gattungs- wie für Artnamen. Artnamen solcher Schriftsteller, welche nicht die binäre Nomenclatur im Princip angewendet haben, können nicht berücksichtigt werden, auch

wenn solche zufällig den Gesetzen der binären Nomenclatur entspre-
chen. Daher sind z. B. Brisson's Gattungsnamen anzunehmen, seine
Artnamen aber sämmtlich zu verwerfen."

The only dissenting voice was that of Prof. Alfred Newton, of
Cambridge, England, who in a vitriolic letter denounced the A. O. U.
Code and upheld the Stricklandian Code as modified in 1865 by the
committee of which he himself had been a member.

It is now worth repeating that in 1891 the A. O. U. Code; the Code
of the Zoological Society of France; the International Zoological
Code; and the International Ornithological Code (on German initia-
tive), all had agreed to start from 1758 and to admit the genus de-
nominations but not the species denominations of all subsequent
authors even though they were not binominalists. Furthermore, while
the British zoologists still adhered to 1766, they nevertheless made a
special exception for generic names proposed by certain authors
(Brisson, Artedi, Scopoli) *before* that date.

The German Zoological Society, founded in 1890, at its first annual
meeting, Leipzig, 1891, entered the field of zoological nomenclature
by electing a commission, consisting of Carus, Döderlein and Möbius,
with the object of preparing a proposition for the " einheitliche Re-
gelung der systematischen Nomenclatur." A preliminary discussion
of the first draft took place at the second annual meeting in Berlin
(1892).—Finally, at the third annual meeting in Göttingen, the final
report, " Regeln für die wissenschaftliche Benennung der Thiere,"
edited by Bütschli, Carus, Döderlein, Ehlers, Ludwig, Möbius,
Schulze, and Spengel, was adopted (Verh. Deutsch. Zool. Ges., Dritt.
Jahresvers., Göttingen, 24 bis 26 Mai, 1893, pp. 89-98).

While this German code in many respects agrees with the Ameri-
can, French and International codes, it is diametrically opposed to
them in that particular matter which we are discussing here. Article 7
is as follows: " Die Anwendung des Prioritätsgesetzes beginnt mit
der zehnten Ausgabe von Linné's ' Systema Naturae ' (1758).
(a) Unzulässig sind Art-und Gattungsnamen aus solchen Druck-
schriften, in welchen die binäre Nomenclatur nicht principiell zur
Anwendung kommt." As the previous German codes employ binär
for binominal or binomial, the meaning of article 7 is unmistakable.
According to it the generic names of Brisson, Gronovius, etc., even
if published after 1758, are not available on the authority of their
first proposers. Thus a new element of discord had entered the arena.

The third International Zoological Congress at Leiden, 1895, there-
fore elected a commission to study the question, consisting of
Blanchard, Carus, Jentink, Sclater and Stiles, who met at Baden-

Baden August 5-7, 1897. The International [Paris-Moscow] Code was made the basis for the revision which was to be presented to the Congress at its coming meeting in Cambridge, England, in 1898. This revision, containing 61 articles in the French language edited by Blanchard (Bull. Soc. Zool. France, 1897, pp. 173-185), followed as closely as possible the sequence of the original [Paris-Moscow] International Code. Carus and Stiles were to present an official version in German and English, respectively, with the understanding that the French text was to be considered standard in case of doubt of interpretation. However, in presenting their individual reports side by side under one cover (Leipzig, Breitkopf and Härtel, 1898, 33 pp.) they changed the sequence and divided the articles in two sections under " A. Rules," and " B. Recommendations," the former again into 7 chapters, each subdivided into articles numbered from Art. 1 up.

The articles interesting us here are as follows:

BLANCHARD	STILES	CARUS
Art. 1	I. Art. 1	I. Art. 1
La nomenclature adoptée pour les animaux est binominale.	Zoological nomenclature is binominal.	Die zoologische Nomenclatur ist binominal.
	VII. Art. 1	VII. Art. 1
Art. 33	The name of a genus or species can only be that name under which it was first designated, on the condition:	Gültiger Name einer Gattung oder einer Art kann nur der Name sein, mit dem sie zuerst bezeichnet worden ist, unter
Le nom attribué à chaque genre et à chaque espèce ne peut être que celui sous lequel ils ont été le plus anciennement désignés, à la condition: 2°. Que l'auteur ait effectivement entendu appliquer les règles de la nomenclature binaire.	b. That the author has properly applied the principles of binominal nomenclature.	der Bedingung, dasz. b. der Autor den Grundsätzen der binären Nomenclatur folgte.

Several points are to be noted here:

1. Blanchard's version is identical with that of the French Zoological Society and the International (Paris-Moscow) Code, leaving out, however, the word " binaire " in Art. 1, but retaining it in Art. 33.

2. Carus' German version of Art. 1 changes the word binär of the code of the German Zoological Society to binomial, but retains it in Art. 33.

It seems evident that Blanchard's dropping of binaire from Art. 1 and Carus' change of binär in the same article to binomial was due to a compromise, as the article is simply meant to establish the fact

that modern zoological nomenclature is *binominal,* one word for the generic designation and one word for the specific designation. *Binaire* in the French version being superfluous and *binär* in the German version being equivocal, the changes were made accordingly. Both, I suspect, agreed in this in a desire to prevent the official recognition of the trinominal as a category of equal nomenclatorial rank.

But it is certain that Blanchard by retaining the word *binaire* in Article 33 also retained the meaning it had in the former French editions. It is almost equally certain that Carus meant to retain the meaning of *binär* in the German code, viz., as synonymous with binominal.

It may not be out of place here to mention the effort of the British entomologists headed by Lord Walsingham and Sir George Hampson to place before the Zoological Congress at Cambridge some of their wishes with regard to a strict application of the law of priority in entomological work and related questions. They presented to the Congress a memorandum on the " Nomenclature of Lepidoptera " (68 pp.). The significant point is that they were unanimously in favor of 1758 as the starting point and they also unanimously agreed that the adoption of this date would make it unnecessary to make any exceptions in favor of earlier authors, such as had been made in the Stricklandian revised Code of 1865. It was thus made clear that even British zoologists were willing to accept 1758, if thereby they could retain all genera proposed after that date.

At the next (4th) International Zoological Congress at Cambridge, England, 1898, no steps could be taken to smooth away the many differences which had arisen. It was then decided to increase the membership of the Commission on Nomenclature to 15. This commission was instructed to centralize, discuss and elaborate all the questions relative to the zoological nomenclature and to present to the Congress in 1901 a final report on the question. The above mentioned memorandum of the British entomologists was also referred to the commission.

The reinforced commission met at the 5th Zoological Congress in Berlin, 1901. The members were perfectly clear on the point that they were expected to agree unequivocally on one definite proposition and that therefore the representatives of the three competing codes would have to yield on some of their pet contentions in order to obtain perfect agreement. It was realized that disagreement would spell calamity, and nobody wanted to take the responsibility of causing a schism. Nevertheless, a break was threatened several times, and concessions were made only after protracted discussion. The

International (Paris-Moscow) Code was made the basis of the revision and not the codification submitted by Carus (and conditionally adhered to by Stiles) to the Cambridge Congress.

Disagreements manifested themselves at the very first paragraph. It will be remembered that in the original code, the nomenclature was declared to be " *binaire* et *binominale.*"

Dr. Stiles, who was the secretary of the Commission, and the present writer, who had had considerable to do with the framing of the A. O. U. Code (Science, vol. 7, Apr. 23, 1886, p. 374) considered themselves called upon to represent the viewpoint of the American zoologists. While admitting that the system of nomenclature was binary in the sense that generic and subgeneric designations are of a class by themselves and that the specific and subspecific designations belong to a second category,[1] they were not prepared to accept the modern nomenclature as binominal with the subspecifical denomination thrown in as a merely tolerated appendix such as contemplated in the French and German codes. Nor would a declaration that Zoological Nomenclature is binary and trinominal cover the ground. Their view being finally adopted, one of the German members, Dr. von Mährenthal, offered the following substitute:

" Die wissenschaftliche Bennennung der Tiere ist für das Subgenus und alle übergeordneten Kategorien mononominal, für die Species binominal, für die Subspecies trinominal " (the nomenclature of subgenera and higher groups is mononominal, of species binominal, of subspecies trinominal).

This version, which clearly established the modern zoological nomenclature as trinominal as against the former binominal method, being considered sufficiently explicit and embodying the idea of the A. O. U. canons vi and viii, was adopted unanimously (among those voting being Carus, Schulze, v. Mährenthal, Blanchard, Stiles, Stejneger, consequently representatives of all three codes).

The discussion of the Code then progressed article by article, until article 44 (Paris-Moscow Code; art. 33 Blanchard Rep. 1897; Chapt. vii, Art. 1, Stiles-Carus Rep.; art. 25 present Intern. Code), which was read:

" Le nom attribué à chaque genre et à chaque espèce ne peut être que celui sous lequel ils ont été le plus anciennement désignés, à la condition: *b.*—Que l'auteur ait effectivement entendu appliquer les règles de la nomenclature binaire."[2]

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[1] The nomenclature of the A. O. U. Code is still binary in that sense, although trinominal.

[2] Remember that the other versions had practically accepted this identical wording, except Stiles', in which *binominal* was introduced in place of *binaire*.

I have previously shown (p. 11) that this phraseology in the Paris-Moscow Code meant to include the generic names of the *binary* but not *binominal* authors after 1758. Although realizing as a fact that the meaning in the revised edition was the same as in the original edition, nevertheless the present writer—agreeing as I did with the French view and insisting upon as close a conformity as possible with that of the A. O. U.—raised the question whether it would not be advisable to amend the phraseology so as to put the exact meaning beyond any possibility of misinterpretation, especially in view of the fact that the code of the German Zoological Society had a rule to the opposite effect. At this point I was interrupted by Carus, who had rendered the Blanchard (Paris-Moscow) version into German, with the remark that all doubt had been eliminated by the introduction of the new wording of article 1 (art. 2, new Intern. Code) to the effect that the scientific designation of animals is uninominal for sub-genera and genera, etc. In this he was supported by F. E. Schulze and by v. Mährenthal, who was the author of the redrafted article 1. Accepting this as a definite abandonment of the German standpoint as against the united views of the French and American zoologists as well as the English entomologists (and to some extent the Strick-landian code of 1865), I did not insist on a rephrasing of the article, and as no motion had been made, no further formal record was entered. This, then, was the sacrifice made by the German delegation, meeting that made by the French with regard to the right to amend faultily constructed or erroneously spelled names. It should be further remembered that the French had already given in on the question of generic names before 1758. One of the principal objects of the French and American zoologists in adopting the edition of 1758 instead of that of 1766 was the inclusion of the Brissonian and other post-1758 genera without making a special rule of exception for their benefit (as the English had been obliged to do), exceptions to the rules being regarded as particularly obnoxious and to be avoided at any cost. It is my firm conviction that if the German zoologists at the meeting in Berlin had not conceded this point, the attempt to produce a gen-erally accepted International Code would have failed as it had done at Leiden and at Cambridge. The result would have been three or four different codes: The French; the A. O. U. Code, backed by most American zoologists; the German Code, probably also accepted by the Austrian and Scandinavian zoologists; and the English adherents of the revised Stricklandian rules. It will be remembered how long the latter held out even after the new International Code had received the sanction of the rest of the world.

As it was, harmony had been achieved and a single code adopted by practically all zoologists. It is true that the American ornithologists have continued to follow their A. O. U. Code in their Check List of North American Birds, but the differences between the two codes are chiefly of a verbal nature with a somewhat different arrangement, so that in the introduction to the revised edition of the A. O. U. Code it could be truthfully stated (Code of Nomencl., Rev. Ed., 1908, p. xxiii) :

" The latest and by far the most authoritative code, that of the Nomenclature Commission of the International Zoological Congress, issued in 1906, embodies all its [A. O. U.] principles and contains nothing antagonistic to them. A few additional points are covered, and others are treated in greater detail. Thus after the lapse of twenty years, the A. O. U. Code of Nomenclature became practically the official Code of an international association of zoologists."

Moreover, when article 30 of the International Zoological Code was amended in 1907, the A. O. U. canons 21-24 were likewise amended by the bodily acceptance of article 30, I. Z. C.

IV. BINARIANS AND BINOMINALISTS

Whether Tournefort's genera of 1700 are " something quite different " from Linnaeus' conception or not, and whether consequently the " glory " of having invented the " genus " in the sense in which it has been handed down from the great Swede to us belongs to him, may be regarded as immaterial in the present connection. It will be sufficient to repeat here that the Linnaean genus concept assumed definite shape in 1735 with Linnaeus' first edition of his Systema Naturae and was further elaborated and developed in the following editions. The species concept and species terminology, *as distinct from the genus terminology,* developed *pari passu* with the genus concept. In fact, with Linnaeus the *denomination* was at least of equal importance with the *differentiation.* It was to him the " filum Ariadneum " which led out of chaos ; he proclaimed already in 1735 : " Divisio & Denominatio fundamentum nostrae Scientiae sint."

The genus concept of Linnaeus was accepted and applied by practically everyone of his pupils and contemporaries after 1735. It was the identical concept which appears in Artedi's posthumous Ichthyologia, edited by Linnaeus himself in 1738. As a matter of fact, he had already incorporated the Artedian genera in his 1735 scheme : " In Ichthyologia nullam ipse elaboravi Methodum, verum suam nobiscum communicavit summus aevi nostri Ichthyologus, *Petr. Artedi, Suecus,* qui in distinguendis Piscium Generibus Naturalibus, &

Specierum differentiis parem sui non habuit." (I have elaborated no method of my own in the ichthyology, but Petr. Artedi, of Sweden, the greatest ichthyologist of our age, who had not his equal in distinguishing the natural genera and the differential characters of the species of fishes has left us his).

Among the pupils of Linnaeus I need only mention L. T. Gronovius, son of J. F. Gronovius, who sponsored the first edition of his Systema Naturae. The younger Gronovius in 1754 published the first and in 1756 the second volume of Museum Ichthyologicum to which was appended his Amphibiorum Historia. In this work the genera were quoted thus: Syngnathus. Arted. Gen. 1, Linn. Gen. 148 (referring to the 6th edition of Linnaeus, Syst. Nat., 1748); then follows: the generic characters; the species designation (polynominal); the species synonymy; descriptive notes on the specimens and remarks; habitat; vernacular names. In the Amphibiorum Historia the treatment is similar and due reference made to each of the Linnaean genera, only here the quotation reads like this: " Coluber Linn. syst p. 34, Gen. 89." He is consequently as thoroughgoing a binarian as Linnaeus himself.

That Brisson's genus concept did not differ from that of Linnaeus is too well known to need further demonstration. As for his application of it to mammals and birds, it is universally conceded that it was superior to that of Linnaeus himself (and the same may be truthfully said of the Gronovian genera of amphibians). Systematically and nomenclatorially there is no essential difference between the genera of Artedi, Gronovius, Brisson and Linnaeus himself before 1758. Nor did the year 1758 make any difference in this regard. They were all binarians after that date as they were before.

The species concept of these men was also essentially the same. Linnaeus, as we know, already in 1735 treated the species as a systematic unit as definitely separate from the genus as the latter from the order and the order from the class. The two categories he also distinguished nomenclatorially. For the genus he employed a single term consisting of one word; the species he distinguished by another term consisting of one or more words. His genera, in other words, were uninominal (or as others prefer to call them, mononomial) ; the species were to a great extent plurinominal (or polynomial). His was consequently at that time a nomenclature consisting of two terms, a nomenclature which unquestionably is binary. It certainly was not yet fully binominal. The great reform in the name applied to the species was not started on a grand scale until 1753, when Linnaeus substituted the *nomen triviale* for the previous plurinominal desig-

nation of the plant species (Species Plantarum). The animals continued for some time under the old binary plurinominal system, appearing thus in the ninth edition of Systema Naturae of 1756. It was only in 1757, in Hasselquist's Iter Palestinum, that Linnaeus consistently applied the binominal nomenclature to the animals, and in 1758, in the 10th edition of the Systema Naturae, the method is finally extended to all the species of animals then known to him.

The acceptance of the reform was general among his contemporaries. There were at least two notable exceptions, however. These were Brisson and Gronovius, both of whom retained their plurinominal species designations in their work published in the interval between the tenth (1758) and the twelfth (1766) editions of the Systema Naturae. As we have seen, the genera recognized by them and their designations differ in no essentials from those of Linnaeus, but while they consequently remained binarians they were not binominalists.

It has been said about Brisson that, as far as species names are concerned, he did not " play the game " of Linnaeus, that his nomenclature of the species is peculiarly his own, and that consequently it has no standing in a system of nomenclature bearing the name of Linnaeus. However, a comparative examination of the works of the two men does not bear out this contention.

To illustrate the socalled peculiarities of Brisson's system of nomenclature, I submit the following abbreviated list of species of birds (Ornithologie, 1760, vol. 3, pp. iii seqv.) of his Genus:

Passer (vol. 1, p. 36)

1. Passer domesticus
2. Passer montanus
29. Linaria
30. Linaria rubra major
31. Linaria rubra minor
36. Fringilla
37. Montifringilla
50. Serinus
51. Serinus italicus
52. Serinus canarius
54. Chloris, etc.

In all cases where Linnaeus includes the species in the sixth edition (1748) and the Fauna Suecica (1746) Brisson quotes the full reference to these works in every synonymy. When publishing his Orni-

thologie he did not see the 10th edition (1758) until after the 4th volume was printed.[1]

Compare the above list with the following list from Linnaeus' 6th edition (1748) and identically repeated in the 9th edition (1756) of the Systema Naturae:

Fringilla (6 ed., p. 30)

1. Fringilla
2. Fringilla crista flammea
3. Fringilla
4. Carduelis vulgaris
5. Carduelis lapponica
6. Carduelis lulensis
7. Montifringilla
8. Spinus
9. Canaria
10. Linaria major
11. Linaria minor
12. Passer domesticus

Noting that Linnaeus only enumerates species mentioned in his Fauna Suecica, 1746, while Brisson listed all the species known to him, and that Brisson regarded *Carduelis* as a distinct genus, while Linnaeus referred *Chloris* to the genus *Emberiza,* the similarity between Brisson's scheme of 1760 and Linnaeus' of 1748-1756 is so obvious that there is no need of further discussing the claim for originality and peculiarity made in behalf of Brisson's method. Nor is it necessary to repeat that just as Linnaeus was a zoological binarian in 1748-1766, so was Brisson still in 1760 and after. The difference between the two men is only that Brisson did not turn binominalist.

Gronovius, who as we have seen, was a binarian like Linnaeus himself in 1754 (Museum Ichthyologicum) and remained so in his Zoophylacium, published in 1763-1764, added a number of new genera of his own, but they are on the same plane and subject to the same rules. Whenever in his former work (1754) he gave his authority for the generic name, he gives no further reference in 1763, but when in the later work he introduces a genus not before treated of by himself he gives his authority thus: TARDIGRADUS. Brisson. Quadr. gen. 3., or CAPRA. Linn. Syst. Nat. Ed. 10. gen. 31. In enumerating the insects, he credits more than 40 generic names to the 10th edition of

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[1] Allen, Bull. Amer. Mus. Nat. Hist. New York, vol. 28, 1910, p. 319.

Linnaeus.   The specific names of Gronovius are typically pluri-nominals with no peculiarities calling for special comment in this connection.

The above may be summarized as follows:

Linnaean nomenclature before 1758 was binary.

Linnaean nomenclature in 1758 and after was binary and binominal.

Gronovian and Brissonian nomenclature was binary, but not binominal.

The genera of Linnaeus, Gronovius and Brisson were uninominal (mononomial).

The species of Linnaeus, until 1758, and of Gronovius and Brisson, until 1764, were plurinominal (polynomial).

The species of Linnaeus from 1758 were binominal.

The code of the American Ornithological union (1886) legalized the trinominal nomenclature and it may be emphasized that the International Code (1901) is likewise binary and trinominal.

EXPLORATIONS AND FIELD-WORK OF THE SMITHSONIAN INSTITUTION IN 1924

CONTENTS

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EXPLORATIONS AND FIELD-WORK OF THE SMITHSONIAN INSTITUTION IN 1924

INTRODUCTION

Scientific exploration and field-work has from the beginning formed an important phase of the Institution's work in the " increase of knowledge." This pamphlet serves as a preliminary announcement of the work along these lines accomplished during the past calendar year, 1924. The accounts are written and the photographs taken for the most part by the field workers themselves, and the scientific results of many of the expeditions will later be presented fully in the various series of publications of the Institution and its branches. With the very limited funds at its command, the Institution is unable to finance many major expeditions, but it endeavors to cooperate in this work, whenever possible, with other institutions, by furnishing men, materials, etc. The many expeditions initiated or cooperated in by the Institution during the 79 years of its existence have resulted in many important additions to knowledge as well as in valuable and instructive material for exhibition to the public in the U. S. National Museum.[1]

GEOLOGICAL EXPLORATIONS IN THE CANADIAN ROCKIES

Secretary Charles D. Walcott continued geological field-work in the Canadian Rockies of western Alberta for the purpose of completing his reconnaissance study of the pre-Devonian formations north of the Bow Valley.

The field season was most unfavorable owing to cold and stormy weather (see figs. 2, 3) that made it difficult and often impossible to work on forty-two days of the season. Eighteen camps were made while on the trail (see figs. 3, 10), and collections of fossils from typical localities were obtained. Incidentally, the party succeeded in getting a fine pair of mountain sheep and a black-tailed deer for the National Museum. At a beautiful but stormy camp just below Baker Lake the Lyell larches were scattered in clumps on the slopes a little below tree line (fig. 4), and wild flowers occurred in profusion about the small lakes south of the camp (figs. 18, 19). Mrs. Walcott made water-color sketches of sixteen flowers new to her collection.

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[1] See Report on Cooperative Educational and Research Work Carried on by the Smithsonian Institution and its Branches, Smithsonian Misc. Coll., Vol. 76, No. 4, 1923.

Looking northeast from the Northern Point of Brachiopod Mountain and the Upper Baker Lake across Oyster Peak and Ridge, Cotton Grass and Tilted Mountain Cirques, Tilted Mountain, Sawback Range Ridges, and Brachiopod Mountain to the southeastern end of Baker Lake. (C. D. Walcott, 1924.)

Fig. 2.—North end of Oyster Mountain near head of Red Deer River Canyon Valley after an August snow squall, northeast of Canadian Pacific Railway, Alberta. (C. D. Walcott, 1924.)

Fig. 3.—Walcott Camp, beside Upper Baker Creek, a short distance below Baker Lake, on a snowy morning. Eight miles (12.9 km.) in a direct line northeast of Lake Louise Station, on the Canadian Pacific Railway, Canada. (Mary V. Walcott, 1924.)
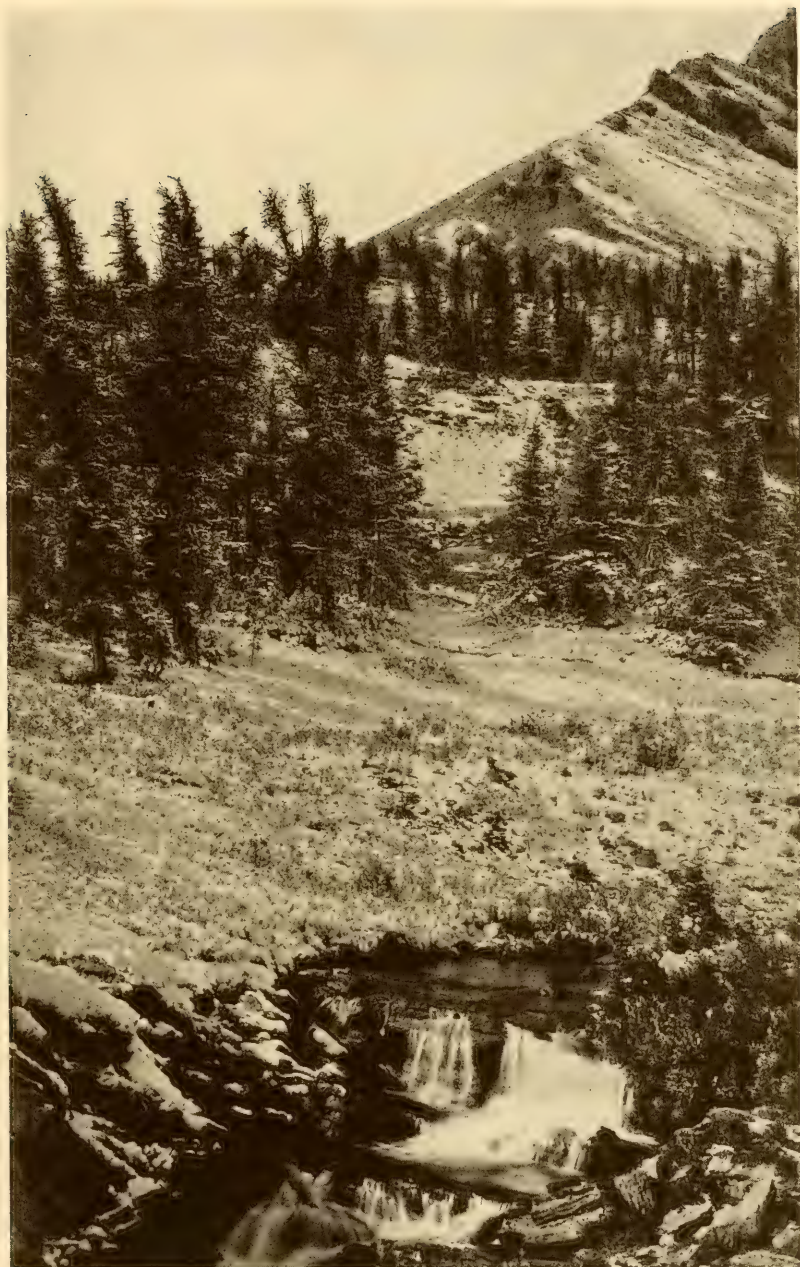
FIG. 4.—Outlook from camp east of Baker Lake. The Lyell larches extend up the slope to tree line. (C. D. Walcott, 1924.)

Fig. 5.—Cotton grass tufted seed heads from Cotton Grass Cirque.
(C. D. Walcott, 1924.)

Fig. 6.—Enlargement of cotton grass seed heads from Cotton Grass Cirque.
(C. D. Walcott, 1924.)

FIG. 7.—Tilted Mountain Cirque with Upper Cambrian strata of the Bosworth Formation tilted up against horizontal Devonian limestones near the head of the cirque. Upturned Upper Cambrian Lyell limestones on the right. (C. D. Walcott, 1924.)

The main objective was to find fossils in the great Lyell lime-
stone[1] in order to determine its position in the scheme of classifica-
tion. Many attempts have been made during the past six years, but
without success, as the thick-bedded, coarse magnesian limestones
were uniformly unfossiliferous except for the presence of a few

Fig. 8.—Tilted Mountain Falls, west foot of Tilted Mountain and north-
east of Lake Louise Station, on the Canadian Pacific Railway, Alberta.
Water flowing over thick-bedded magnesian Upper Cambrian Lyell lime-
stones. (C. D. Walcott, 1924.)

casts of worm trails and the cylindrical structures supposedly built
up by the secretions of algal growth, both of which may occur in
sedimentary formations from the pre-Cambrian to the present day.
In measuring a section from Fossil Mountain (fig. 1) eastward
into Oyster Mountain, the Lyell limestones were found to form the
main north and south ridge, and in two large, glacial cirques cutting

[1] Smithsonian Misc. Coll., Vol. 72, No. 1, 1920, p. 15.

deep into the ridge, the base of the Lyell was uncovered (fig. 1), as well as the oolitic limestones and shales of the Bosworth formation[1] that are so finely exposed in Mt. Bosworth on the Continental Divide above Kicking Horse Pass near Wapta Lake. The most northern cirque was named Cotton Grass from the presence of large areas of the beautiful cotton grass tufted seed heads (figs. 5, 6). The southern cirque (fig. 7) almost cuts through Tilted Mountain and bears its name. Mountain sheep have a trail up the

FIG. 9.—Rocky Mountains Park warden cabin, on Panther River, opposite the mouth of Snow Creek. (C. D. Walcott, 1924.)

cirque and over into Douglas Lake Canyon valley and onto the northern ice and snow fields of Bonnet Peak. In figure 7 the Lyell limestones, with the more readily eroded Bosworth beds below, were pushed eastward and the latter are tilted up against the horizontally-bedded massive Devonian limestones, forming the broadly and smoothly rounded mountain at the head of the cirque. We followed the brook running out of the little glacial lake in the bottom of the cirque in its course westward over the ledges of Lyell limestones to the falls, where it slides and falls into the canyon valley of upper Baker Creek (fig. 8) but everywhere the same hard, thick-bedded,

[1] Smithsonian Misc. Coll., Vol. 53, No. 5, 1908, p. 205.

light gray limestone extended in all directions until near the edge of the sloping cliffs above the canyon valley, where long narrow strips of trees and grass covered spaces occurred between the north and south ledges. Another approach was made from the south side of the brook, and an outcrop of a few thin layers of bluish-gray limestone was encountered on a small, rounded, glaciated ridge of the

Fig. 10.—Camp on north slope of Burgess Pass, B. C., from which the Burgess shale quarry was worked for several years. This is a typical camp where grass for horses, firewood and water are close at hand. (C. D. Walcott, 1924.)

magnesian Lyell limestone. These bluish-gray layers were interbedded in the Lyell, and contained fragments of Upper Cambrian trilobites. Returning another day, the thin band of bluish-gray limestone was traced to the brook and in a small narrow canyon two bands of shale and bluish-gray limestone were found a little lower in the section. The lowest band was rich in fragments of trilobites that later were found to be closely related to Upper Cambrian Franconia trilobites

FIG. 11.—Mountain sheep at a salt lick in the Red Deer River below the "Falls" near mouth of McConnell Creek. The party brought in three fine sheep heads and skins for the National Museum collections. (Mrs. Mary V. Walcott, 1924.)
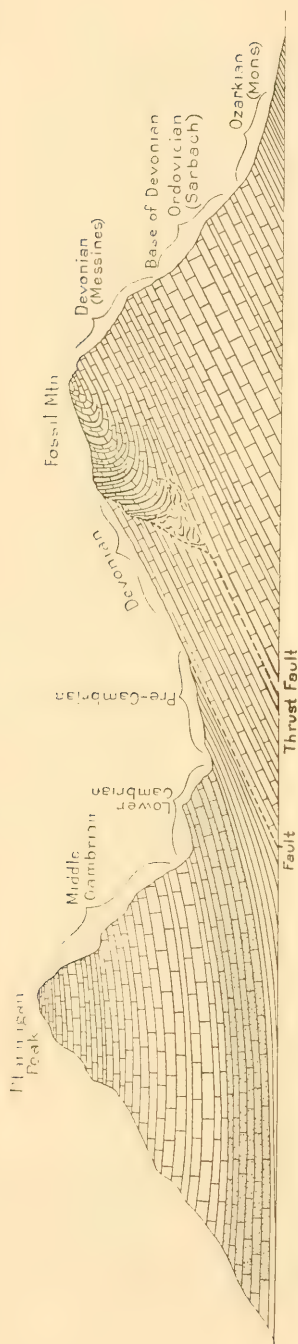
Fig. 12.—Diagrammatic section of the geological formations occurring in Ptarmigan Peak and Fossil Mountain (see fig. 15) illustrating the position of the strata and the over-thrusting of the Ptarmigan Peak pre-Cambrian sandy shales on the Devonian limestones.
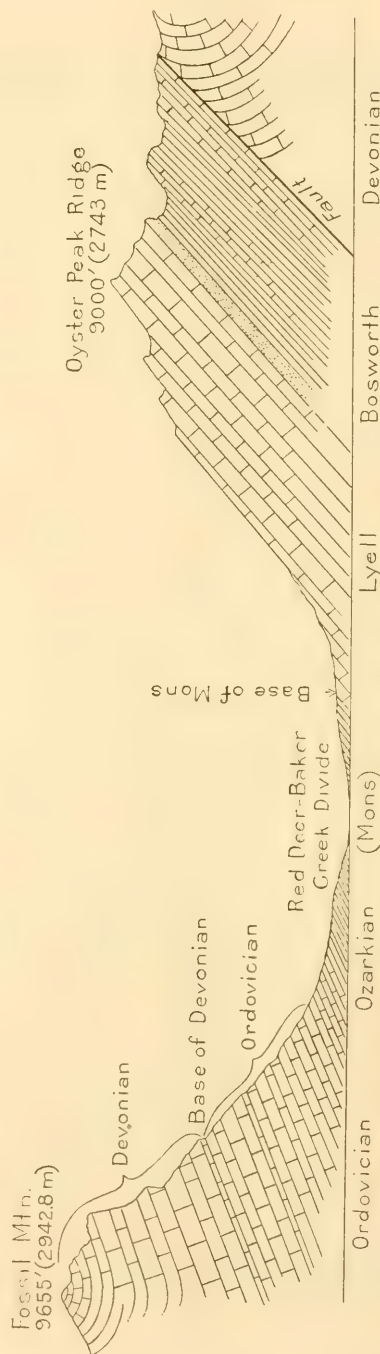
Fig. 13.—Diagrammatic section of Fossil Mountain across Red Deer-Baker Creek Divide and the north side of Cotton Grass Cirque, Oyster Peak Ridge. This section was measured and studied in 1924 and the left half of the panoramic view, figure 1, illustrates its character as seen by the camera.

Section Mt. (9000'+)

FIG. 14.—Cliffs on the north side of the Upper Clearwater River, in which the pre-Devonian section is similar to that of Fossil Mountain. D = Devonian, S = Sarbach of the Ordovician, M = Mons of Ozarkian, and L = Lyell of Upper Cambrian. (C. D. Walcott, 1924.)

Brachiopod Mt.   Ptarmigan Peak (10,070')   Fossil Mt. (9665')

FIG. 15.—Panoramic view of east and south face of Fossil Mountain; on the right Ptarmigan Peak with its basal beds thrust over onto the limestones of Fossil Mountain in the center, and on the left the end of Brachiopod Mountain with a great mass of limestone that has broken away from the mountain. Baker Lake in central foreground is 8 miles (12.9 km.) east of Lake Louise Station. (C. D. Walcott, 1924.)

from Wisconsin, and the fauna of the upper band was found to be of the same type as the fauna of the St. Lawrence member of the Trempealeau formation of Wisconsin. With these two faunules definitely located in the upper portion of the Lyell limestones, we now know that the latter are of Upper Cambrian age, and thus is brought to a successful conclusion a search conducted for four field seasons
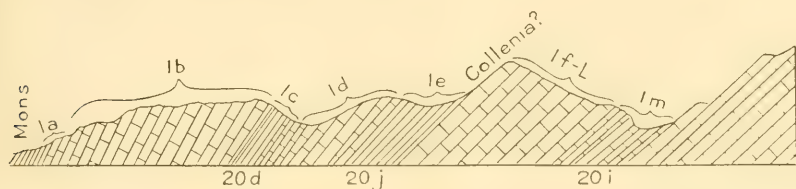
Fig. 16.—Diagrammatic section of the Upper Lyell at Tilted Mountain Falls (see fig. 8). 1^a = Arenaceous beds at contact of Lyell and Mons formations; 1^b, 1^d, 1^{f-1}, gray magnesian limestones; 1^c, 1^e, 1^m, fossiliferous bands of shale and gray limestone. (C. D. Walcott, 1924.)
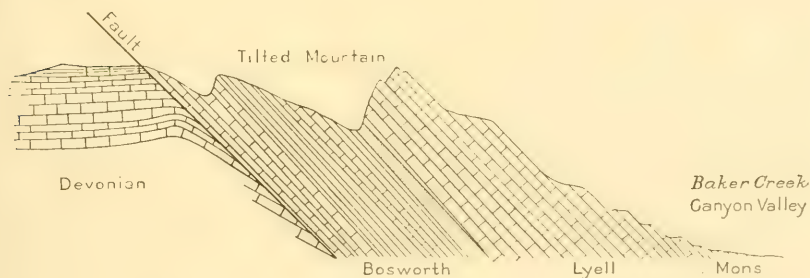
Fig. 17.—Diagrammatic section of Tilted Mountain interpreting the geologic structure, as shown by fig. 7. (C. D. Walcott, 1924.)

to determine the position of Lyell limestones in the Upper Cambrian series of the Canadian Rockies.

With the Lyell question out of the way, further collections were made from the Ozarkian upper Mons limestones of Fossil Mountain before going to Wild Flower Canyon. The latter is referred to in the account of exploration in 1921.[1] It heads on Johnston Creek Pass and extends in a northwesterly direction to where it joins Baker Creek Canyon. The gray limestones of the Mons formations form the high ridge on its northeast side and in these were collected many

[1] Smithsonian Misc. Coll., Vol. 72, No. 15, 1922, pp. 8, 9.

Fig. 18.—Arrow-leaved Coltsfoot (*Petasites sagittata*) from Burgess Pass, British Columbia. (Mrs. Mary V. Walcott, 1924.)

Fig. 19.—Sweet Androsace (*Androsace carinata*) from Baker Lake, Alberta. (Mrs. Mary V. Walcott, 1924.)

specimens of the upper Mons faunules. Early in September, the party crossed to the head of the Red Deer River and followed it down to where it breaks through the eastward-facing cliffs of Devonian limestone which have been thrust eastward over onto the sandstones, shales and limestones of the Cretaceous formations of the " foothills." It was expected to secure some fine photographs of interesting structural geology but the continuous cloudy and rainy weather prevented. On the ridge between the Red Deer and Panther Rivers at Snow Creek (fig. 9) a very fine pair of sheep was obtained and

Fig. 20.—Cricket, faithful 21-year-old saddle horse, the wisest one of the bunch of horses. She is waiting for a crust of bread. (C. D. W.)

unusually fine trout were caught below Eagle Pass north of the Red Deer River, also in Baker Creek earlier in the season. As hunting and fishing are only incidental to the geological work and Mrs. Walcott's wild flower studies, it is only on rainy days or after the day's work is over that the men indulge in sport. At a " lick " beside the Red Deer River, many mountain sheep were seen (fig. 11) and on the trail, moose, deer, goats, and smaller mammals were met with, especially about Baker Lake and in the Red Deer Canyon.

Some progress has been made the past eight field seasons towards a better understanding of the pre-Devonian geological formations and

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their contained faunas in the Canadian Rockies, but there is a great opportunity for the young, vigorous geologist and paleontologist to add to knowledge of them for many years to come, especially between the Canadian Pacific Railway and the Arctic Ocean.
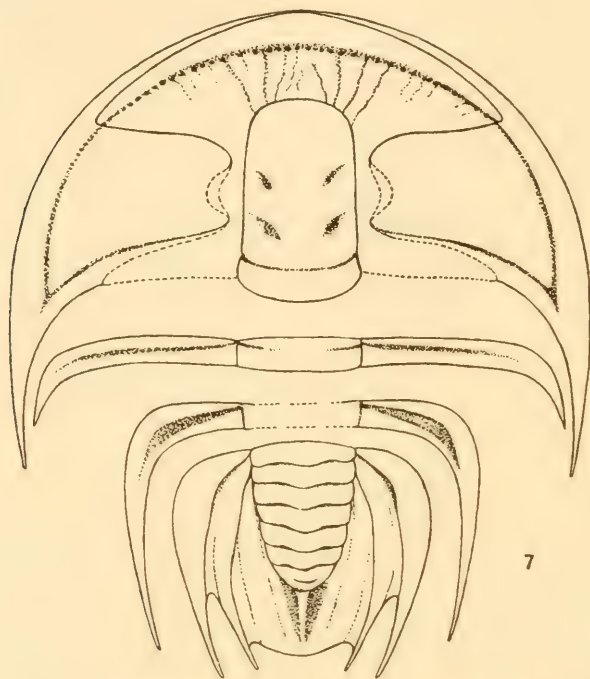
FIG. 21.—*Kainella billingsi* (Walcott). This large, fine trilobite loses its former generic name *Hungaia*,[1] as a species referred to *Hungaia* was published in a list of Upper Cambrian fossils in 1914 as *Hungaia magnificus* Billings.[2] The genus *Kainella* is now proposed with the species *billingsi* Walcott as the genotype. Other species occur that will be described in a subsequent paper. The name *Kainella* is derived from Mount Kain (9,392 feet, 2,862.7 m.), which was named after Conrad Kain, a noted Swiss guide and Alpine climber. It is located southeast of Billings Butte and Robson Peak, British Columbia, Canada.

As in previous years, assistance was freely given by Commissioner J. B. Harkin and the members of the Canadian National Parks Service, and the officials and employees of the Canadian Pacific Railway. The expedition was greatly aided by grants from the O. C. Marsh and Joseph Henry endowment funds' of the National Academy of Sciences.

[1] Smithsonian Misc. Coll., Vol. 75, No. 1, 1924, p. 37, fig. 7, p. 38.
[2] Loc. cit., Vol. 57, No. 13, 1914, p. 351.

GEOLOGICAL FIELD-WORK IN TENNESSEE

In the field season of 1924, R. S. Bassler, curator of paleontology, U. S. National Museum, continued geologic work in Tennessee commenced several years ago in cooperation with the Geological Survey of Tennessee under the direction of State Geologist Wilbur A. Nelson. In previous seasons the geology and paleontology of the Central Basin were studied, followed in 1923 by an investigation of the eastern portion of the surrounding Highland Rim. In 1924 the Highland Rim work was carried northward to the Kentucky-Tennessee boundary where an area of about 125 square miles comprised in the Lillydale quadrangle of the Cumberland River district was mapped in detail. The primary object of this mapping was an economic one for the geologic structure of the region gives it oil possibilities. This area is far from railroad facilities and transportation is by the Cumberland River, when high enough, automobile sometimes, but most often by horseback. The method of transporting gasoline is shown in figure 22.

The Highland Rim of Tennessee is the plateau area averaging a thousand feet elevation surrounding the Central Basin. It is usually so flat that the underlying rocks are seldom exposed but in the Lillydale quadrangle the Cumberland River and its tributaries have cut so deeply into the Rim that the topography is very rough and the strata are exposed at frequent intervals. Here the exposed strata range in age from the Catheys (Trenton) limestone of the Middle Ordovician to the Cypress sandstone of the Chester group near the close of the Mississippian. The Catheys limestone and the succeeding Leipers limestone of Upper Ordovician age are followed directly by the Chattanooga black shale of Early Mississippian time, all Silurian and Devonian strata being absent. The black shale formation is only 20 feet thick in this area but it is so widely distributed that the geologic structure of the region is best determined by its outcrops. All of the strata here are essentially horizontal, but by plotting the elevation above sea level of the base of this black shale from outcrop to outcrop and connecting the places of equal elevation, thereby forming a structure contour map, no less than 20 small but distinct dome-like uplifts were discovered in this quadrangle alone. The formations above and below the black shale exhibit this same structure but the dip is usually so slight as to be almost imperceptible (fig. 23). Some of the domes formed by the uplifted strata (fig. 24) are known to be

FIG. 22.—Transportation methods along Upper Cumberland River, Celina, Tennessee. (Photograph by Bassler.)

FIG. 23.—Slightly dipping Upper Ordovician limestone, Clay County, Tennessee. (Photograph by Bassler.)

FIG. 24.—Part of an oil structure along Kettle Creek, northern Tennessee.
(Photograph by Bassler.)

FIG. 25.—Drilling for oil, Neely's Fork, Clay County, Tennessee.
(Photograph by Bassler.)

oil reservoirs and drilling is being actively pursued on such areas
(fig. 25).

From a paleontological standpoint, the Mississippian formations
following the black shale were of highest interest. Usually in Ten-
nessee the rather unfossiliferous Fort Payne chert of Keokuk age
succeeds the Chattanooga black shale but in parts of the Lillydale
quadrangle two intervening formations were discovered. These were:
first, the Ridgetop shale of Kinderhook age reaching a thickness of
200 feet, and second, the richly fossiliferous New Providence shale
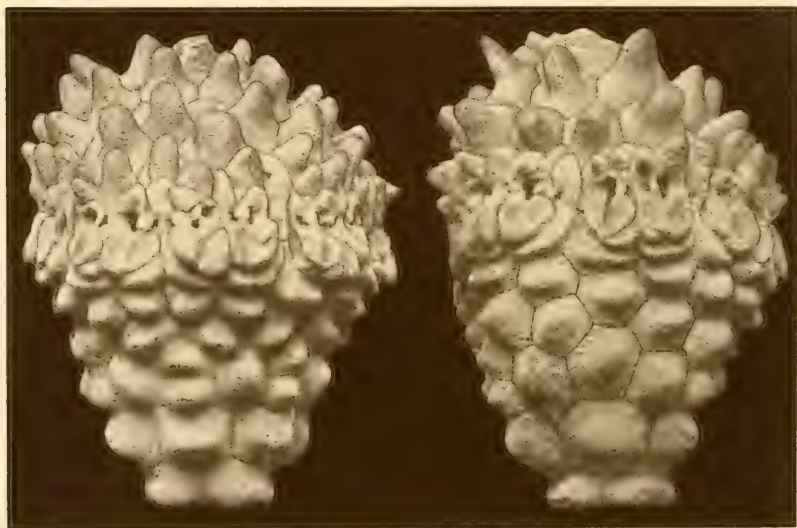
Fig. 26.—*Batocrinus springeranus* Bassler, a new species from the Lower
Keokuk, Overton County, Tennessee; slightly less than natural size. (Pho-
tograph by Bassler.)

of Burlington age noted particularly for its crinoid fossils. Detailed
mapping showed that these two formations were not deposited over a
wide area but that they occupied ancient embayments of the sea
surrounding the Cincinnati anticline. The succeeding strata in the
quadrangle are of Keokuk, Warsaw, St. Louis and Chester age and
show a more uniform, widespread development. The Keokuk lime-
stone, however, exhibited different characteristics from its usual devel-
opment in Tennessee as the Fort Payne chert, but the relationships
between these strata will have to be determined from future studies
of a more extended area. Paleontologically this formation in the

Lillydale quadrangle was of particular interest in that the basal beds afforded a splendid fauna of crinoids many of which are new to science. One of these new species, named in honor of the eminent specialist, Dr. Frank Springer, is illustrated herewith (fig. 26).

GEOLOGICAL FIELD-WORK IN THE ROCKY MOUNTAINS

During August and September, 1924, Dr. Charles E. Resser, associate curator of paleontology, U. S. National Museum, under the direction of Secretary Charles D. Walcott, continued the study of the Cambrian formations in the Rocky Mountains, using the Ford truck and camp equipment purchased the previous season. He was accompanied and ably assisted by Mr. Robert S. Bassler, of Washington, D. C.

At the invitation of Prof. L. A. Keyte, Colorado College, Colorado Springs, Colorado, the first stop was at that place and several days were spent studying the lower Paleozoic beds along the Rocky Mountain front. Under Professor Keyte's guidance and with his automobile, no delay was experienced in locating fossiliferous outcrops and securing good collections. During the past few years this region has yielded many very excellent Ozarkian fossils, new to our study series.

Work was continued in Logan Canyon, Utah, to ascertain whether any beds of Ozarkian age, which occur 30 miles to the south in Blacksmith Fork Canyon, outcrop at this place. A snowstorm prevented the completion of this task the previous September, but this year it was found that the lower beds sought are not present.

Camp was then moved by rapid stages to the Cooke City Ranger station in the extreme northeastern corner of Yellowstone National Park. A most excellent section exposing most of the Cambrian formation present in this part of the Rocky Mountains (Absaroka Mountains) was measured up Republic Creek, south of Cooke City, Montana. Cooke City is a small community which came into existence upon the discovery of silver ores in the surrounding mountains. It can be reached by only one road which enters the Yellowstone Park at Gardner, Montana, and branches off of the "Loop System" of roads at Camp Roosevelt, following first the Lamar River past the Buffalo Ranch, and then up Soda Butte Creek, a total distance of more than 70 miles. On all other sides high mountains hem it in and since the ores have never proven rich enough to compensate for the town's isolation, the mines are undeveloped and the population is sparse. The road to Cooke City traverses the best of the mountain

scenery in Yellowstone Park. One member of the Cambrian series of beds is always massive and since Soda Butte Creek has cut into a gently dipping fold, this massive limestone rims the valley. Every stream, permanent and temporary, falls over this layer, usually in a very narrow canyon, adding very much to the picturesqueness of the region. Indeed, Cooke City is coming to be a favored tourist resort. Immediately above the massive limestone just mentioned, the beds become shaly, and from these were secured an entire Cambrian crinoid of which no complete individual had previously been discovered in rocks as ancient as these. However, the fossils obtained from this

Fig. 27.—Jackson Lake and Mt. Moran. The Grand Teton visible to the south. The dead timber along shore is caused by flooding when dam fills. (Photograph by Resser.)

excellent section were few in number compared to what might be expected from such a group of Cambrian beds, due to their deposition in shallow water. At many places the rocks are composed almost entirely of fossil fragments which had been ground up by the waves prior to preservation.

A brief trip was made into the south end of the Gallatin Range, to secure a few fossils in order to determine the relationship of the Cambrian beds present here to those in the Absaroka and Teton Ranges.

Work was next continued in the Teton Mountains, which are in many respects the most magnificent in the United States, rising as they

do into sharp, steep peaks more than 7,000 feet above the deep
Jackson Lake. A dam has been built at the former outlet of the lake,
impounding the flood waters to a depth of 39 feet, thus preserving
an enormous quantity of water for irrigation in the Snake River
Valley, 300 miles away. The Teton Mountains, due to their rugged-
ness, and the extensive lakes at their base, proved more than ordinarily
difficult to work from an automobile. They present, however, many
interesting and some unique geological problems. This range con-
sists of highly tilted Archaean rocks on the eastern face overlain from

FIG. 28.—View south from Glen Eyrie, Colorado, showing the strata
folded during building of Rocky Mountains, now weathered into upright
forms. Garden of the Gods visible in distance. (Photograph by Resser.)

the west by much less steeply inclined strata which include Cambrian,
Ordovician and younger series. A six-inch layer of relatively pure
iron ore was observed near the base of the Cambrian series. At all
points in the range visited this season it was found that the fossils had
also been broken before being buried.

The highway across Teton Pass, by which one leaves Jackson Hole,
going south and west proved exceedingly steep but highly interesting
and of great beauty. The drainage of Jackson Hole escapes through
the Grand Canyon of the Snake River, cut more than a half mile
deep into the mountain wall closing in the south end of the valley, for
which reason the road cannot follow along it.

FIG. 30.—Republic Creek, south of Cooke City, Montana. Characteristic outcrop of the massive Cambrian limestones in the narrow creek canyons. (Photograph by Resser.)

FIG. 29.—Entrance to Williams Canyon, on road from Manitou Springs to the Cave of the Winds. Several feet of beds at the roadway are Cambrian, the remainder Ozarkian. (Photograph by Resser.)

The past season was the hottest and driest ever recorded for the western part of our country, in consequence of which snow banks that had never been known to disappear, melted away. Most of the mountain streams had little more than a fourth or half of their normal flow and the roads became almost impassable at places because the soil, having turned to soft dust, was blown away leaving large stones exposed. Difficult travel was consequently encountered at many places.

The latter part of the season was spent in continuing the study of various parts of the great Wasatch Range, to determine the stratigraphic position of the beds from which some of the earliest collections of fossils were made by exploring parties sent out previous to the settlement of the country.

GEOLOGICAL FIELD-WORK IN MARYLAND AND CONNECTICUT

Mr. Earl V. Shannon, assistant curator, division of physical and chemical geology, U. S. National Museum, made several short trips into Maryland during the year to visit mineral localities in that state. The most noteworthy was that made in May to Cecil County, where several feldspar quarries and the historically famous locality known as the State Line Chrome Mine were visited. Much material was collected for study. The reopening of the Chrome Mine during the war made available on the dump a quantity of freshly mined rock and a fine series of specimens of chromite, magnesite, kammererite and especially of the precious green serpentine known as williamsite was obtained.

In October, Mr. Shannon made a beginning in the cooperative work with the Geological and Natural History Survey of Connecticut leading toward the publication of a work on the mineralogy of that state. Between two and three weeks was spent in a highly successful collecting trip. A beginning was made in the southeastern corner of the area, including a visit to many of the quarries, mines, and road cuts in Groton, Stonington and Waterford. At the Mason's Island quarry in Stonington, numerous pegmatite dikes occurring in the gneiss were studied and some of them were found to contain notable quantities of primary magnetite. In places biotite-rich streaks in this quarry were found to contain golden-brown stilbite, and in one end of the quarry a quartz vein was located which furnished associated specimens of garnet, epidote, and stilbite. In Salter's quarry in

Fig. 31.—Salters Quarry, Groton, Connecticut. A typical stone quarry like hundreds in New England, any one of which can be depended upon to furnish much interesting mineralogical material.

Fig. 32.—Hungry Hill iolite locality, Guilford, Connecticut. The photograph shows Messrs. Alfred E. Hammer and Warren E. Mumford standing on what is probably the best locality for iolite in North America, if not in the world.

Groton, specimens and notes on peculiar diorite-pegmatites, older than the Westerly granite sills, were obtained and other pegmatites of interest were observed intruding the Mamacoke gneiss which is quarried in the Goos, Flatrock and other quarries in Waterford. One day was spent in examining the various outcrops, cuts, and quarries along the shore line branch of the New York, New Haven and Hartford Railroad from Saybrook Junction to Nantic. Another was spent at the Falls of the Yantic, in Norwich, a famous locality for minerals obtained early in the last century and but little known since. No iolite nor corundum were found, but sillimanite was located in quantity in

FIG. 33.—The main pit of the mine at Long Hill in Trumbull, Connecticut, probably the first tungsten mine of America. While never commercially successful as a tungsten mine and the source of more than one "wildcat" project, this is now a famous mineralogical locality.

a schist in a railroad cut, and plenty of monazite specimens were obtained from pegmatite blocks in fence walls in the neighborhood.

The latter part of the trip was spent at Branford as the guest of Mr. Alfred E. Hammer, who is particularly well informed regarding the local geology and mineralogy and the history of mining in his vicinity. In company with Messrs. Hammer and Warren E. Mumford, metallurgist for the Malleable Iron Fittings Company of Branford, many of the important localities were visited. These included the iolite and garnet-vesuvianite ledges in Guilford, the jail spar quarry, the spessartite ledge and other feldspar quarries in Haddam, and the Gillette quarry on Haddam Neck, where many remarkable minerals

were found. In Middletown the old lead mine, famous as a source of metallic lead for bullets in Revolutionary days, was examined. The Cheshire barite-copper mine and the trap quarry on Mt. Carmel were visited, and the last trip of the season included a visit to the now famous mineralogical locality of the tungsten mine at Long Hill in Trumbull. On this trip the old Booth-Curtis bismuth mine in Monroe, long a source of native bismuth specimens, was located, but too late to secure extensive collections.

GEOLOGICAL FIELD-WORK IN NEVADA

During the four months, June to September, Dr. W. F. Foshag, assistant curator of mineralogy, U. S. National Museum, worked in

Fig. 34.—Walker Lake, Nevada, showing the old shore lines of Lake Lahontan.

cooperation with one of the U. S. Geological Survey field parties in the mapping of the Hawthorne quadrangle, western Nevada, making a special study of the mineralogy and ore deposits of the area. Besides Paleozoic and Mesozoic sedimentary rocks, Cretaceous granites and Tertiary lavas, the area embraced a number of interesting lake beds of Miocene, Pliocene and Pleistocene age, in which were found the remains of fishes, fresh water gastropods, plants, and the bones and teeth of horses, camels, mastodon, and rhinoceros. A reported occurrence of artifacts in the beds of the extinct lake Lahontan, Pleistocene

Fig. 36.—Wind pot holes.
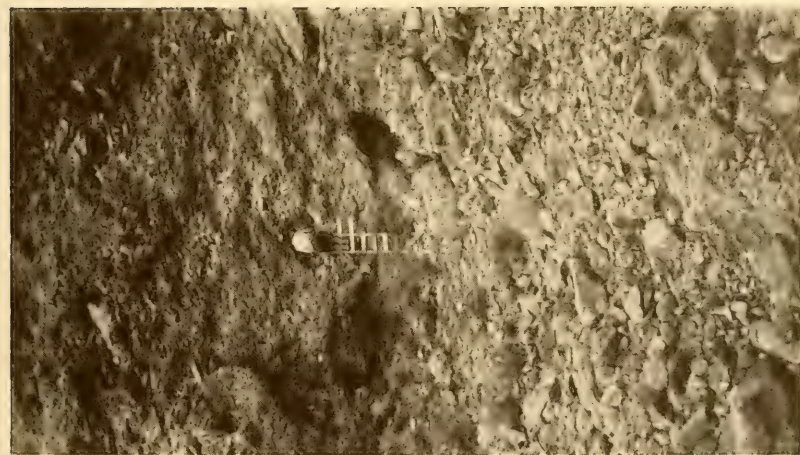
Fig. 35.—Collecting camel bones, Lahontan gravels, Walker Lake.
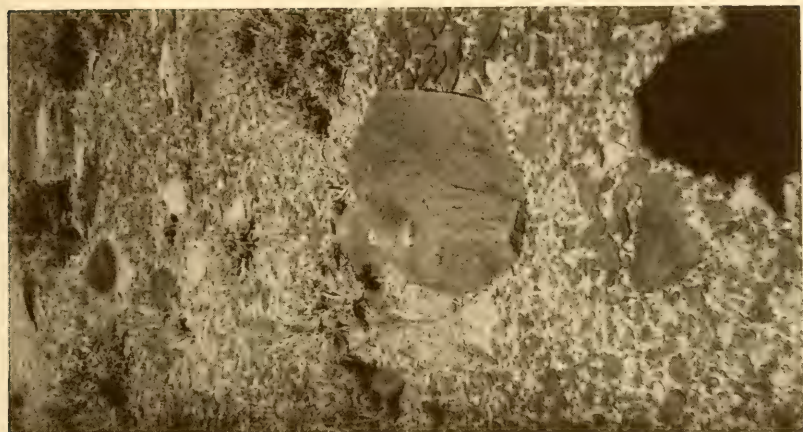
in age, was visited and examined in detail. Flakes of obsidian such as are found in abundance throughout this area were noted but no ancient artifacts or other evidence of Pleistocene man were found.

Some time was devoted to a study of ore deposits of the region including those of the historic old camps of Candelaria and Aurora and also those more recent. The mercury deposits of the Pilot Mountains were studied in some detail and interesting collections made. The quadrangle is' unusually rich in minerals and much material was collected for study. This came largely from the mines and prospects of the region, but some unusually fine material was also recovered from the muds of the " playa " lakes.

FIELD-WORK OF THE ASTROPHYSICAL OBSERVATORY IN CHILE, ARIZONA, AND CALIFORNIA

The Astrophysical Observatory continued its work on the sun's heat and the variations of it. More and more interest is being expressed in this work because it promises to be a basis for advances in weather forecasting. At first sight, the problem is very simple. As the temperature and rainfall of the earth depend on the sun's heat, a change in the sun's heat must modify temperature and rainfall. Actually, however, the effects are highly involved.

To explain the matter briefly, there are always certain regions of high and others of low barometric pressure. These are centers of atmospheric circulation. The word circulation is indeed more expressive than we often think, for the wind directions bend around these centers of circulation. Meteorologists speak of cyclones and anticyclones, meaning the great rotary tendencies of the winds over areas hundreds of miles in diameter, associated respectively with barometric lows and highs. Such being the case it depends at least partly on the observer's position, relative to one of these atmospheric centers of circulation, whether his weather is warm or cold. For winds from warmer latitudes tend to make warm weather, and winds from colder ones cold weather.

If, now, the effect of increase of the solar heating acting upon the highly complex surface of the earth, with its mountains, deserts, oceans, etc., should tend to displace an atmospheric action center (toward the pole, for instance) a station which previously received prevailingly tropical winds might afterwards receive prevailingly polar winds, and thereby be *cooled*, not *warmed*, by the supposed increase of solar heat. Another station, a few hundred miles away, might experience the very opposite effect from the same cause.

On such grounds we have not to expect any simple or easy solution of the problem of the influence of variations of the sun on our weather. Apparently there is only one way to proceed. It is to observe diligently and accurately for years the sun's changes of radiation, and then, with the basis of fact so laid, examine the behavior of atmospheric pressure, temperature and rainfall at a great number of stations over all the world, at all times of the year, in order to work out at last the exact dependence of weather on solar changes.

This is a very large program. The Astrophysical Observatory began with it in 1902, when it commenced to observe the solar radiation in Washington. But the atmosphere in Washington was loaded with clouds, smoke, dust and humidity. It was necessary to remove to a purer sky. Since then stations have been occupied as follows: Mt. Wilson, Calif., during summer and autumn, 1905 to 1920; Mt. Whitney, Calif. (the highest mountain of the United States outside Alaska) on several days in 1908, 1909, and 1910; Bassour, Algeria, in summer and autumn 1911 and 1912; Hump Mountain, N. C., almost a full year beginning May, 1917; Calama, Chile, July, 1918, to July, 1920; Montezuma, Chile, August, 1920, to the present time; Mt. Harqua Hala, Ariz., October, 1920, to the present time.

During all this time better and better methods have been developed, obstacles to accuracy overcome, and new sources of error recognized and avoided. The body of experience which has thus come to the members of the staff is unique, and a very great asset. There is, indeed, the highest necessity for it. The results of Mr. H. H. Clayton, who has attempted with much success to unravel the effects of solar changes on the weather, indicate that variations of the sun as small as 0.5 per cent, or 1/200 of the whole solar output, produce well recognizable effects. Changes greater than 3 per cent do not often occur, though once in a great while they go even higher than 5 per cent. Observing, as we do, at the bottom of a sea of atmosphere, loaded more or less with variable elements, like dust, water vapor, etc., it is very difficult to reach a high enough standard of accuracy to reveal surely changes as small as these.

During the past four years, with the newest methods of observation and computation, our two observing stations in Arizona and Chile each determined the sun's heat on upwards of 70 per cent of all days. Taking all fairly good days when both stations observed, the average deviation of these independent measures, made over 4,000 miles apart and reduced independently for atmospheric losses, is about 0.5 per cent. During October, 1923, however, both stations reported almost every day, and the average daily difference was less than 0.2 per cent.

It would be highly advantageous to have another pair of stations located, if possible, in well separated cloudless regions where the months December to March are more favorable.
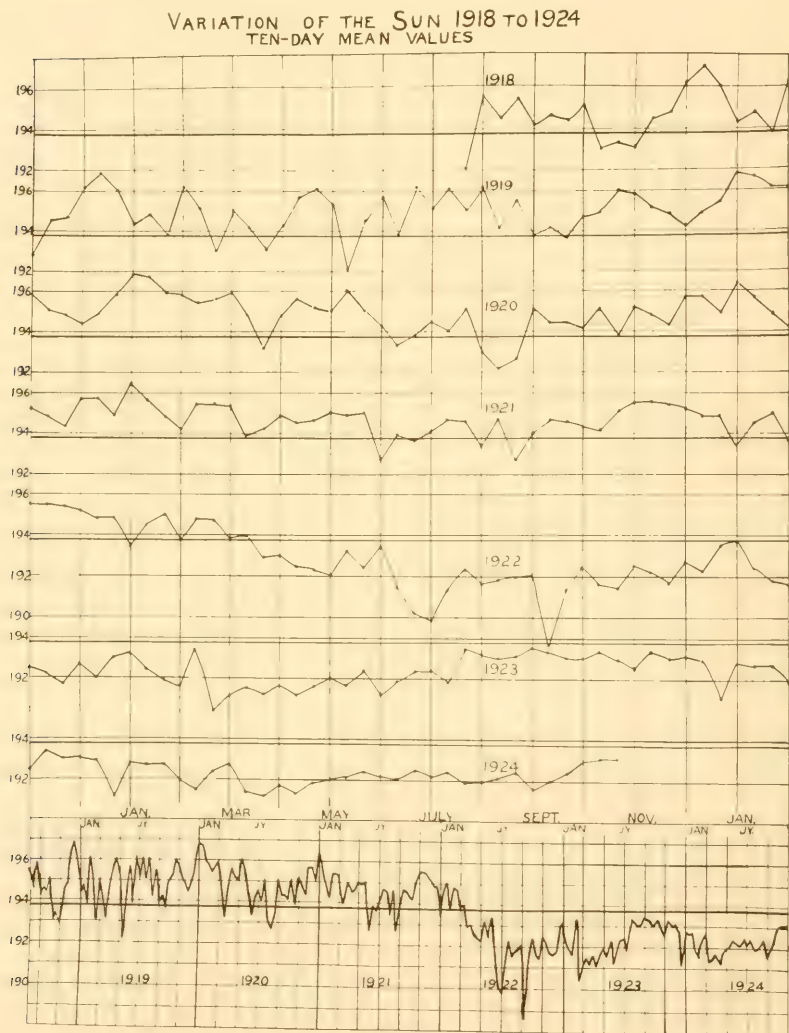
Fig. 37.

On the whole, the solar heat appears to have been continuously below the normal for the past $2\frac{1}{2}$ years. Of late months the tendency to rise has become apparent, so that it seems likely that higher values

will soon prevail again. We had hitherto noted an association of higher solar radiation with greater sun-spot activity. (See fig. 38.) As we have now passed the minimum of sun-spots, and greater solar activity is to be expected in the next years, the rising tendency of the solar radiation is not surprising.

During the past year, the Institution has received each morning telegrams from Arizona and Chile giving the solar results of the preceding
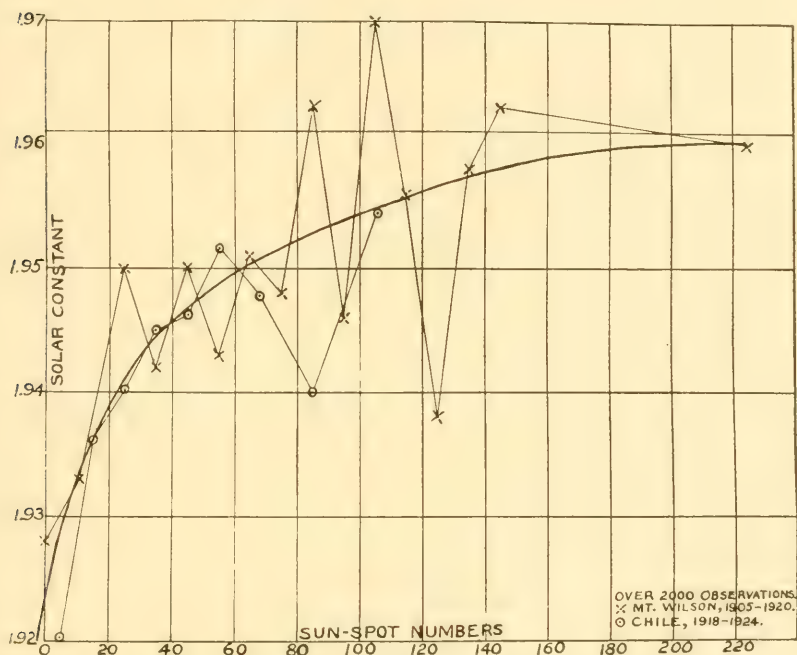
Fig. 38.—Increased solar activity brings higher solar-constant values.

day, and has forwarded the combined result by telegraph to Mr. H. H. Clayton in Massachusetts. Mr. Clayton has returned to the Institution on the same afternoon a letter giving forecasts for the temperature of New York City several days in advance. Mathematical methods, independent of personal bias, show that these forecasts indicate some degree of real prevision, based on the solar observations, even to 5 days in advance. These investigations are supported by Mr. John A. Roebling. A continuation of them is intended.

Interesting results were secured in quite a different field. Dr. Abbot employed a Nichols radiometer in connection with the 100-inch reflect-

ing telescope of Mt. Wilson Observatory. He not only could observe the heat of the brighter stars, but, separating this into a long spectrum,
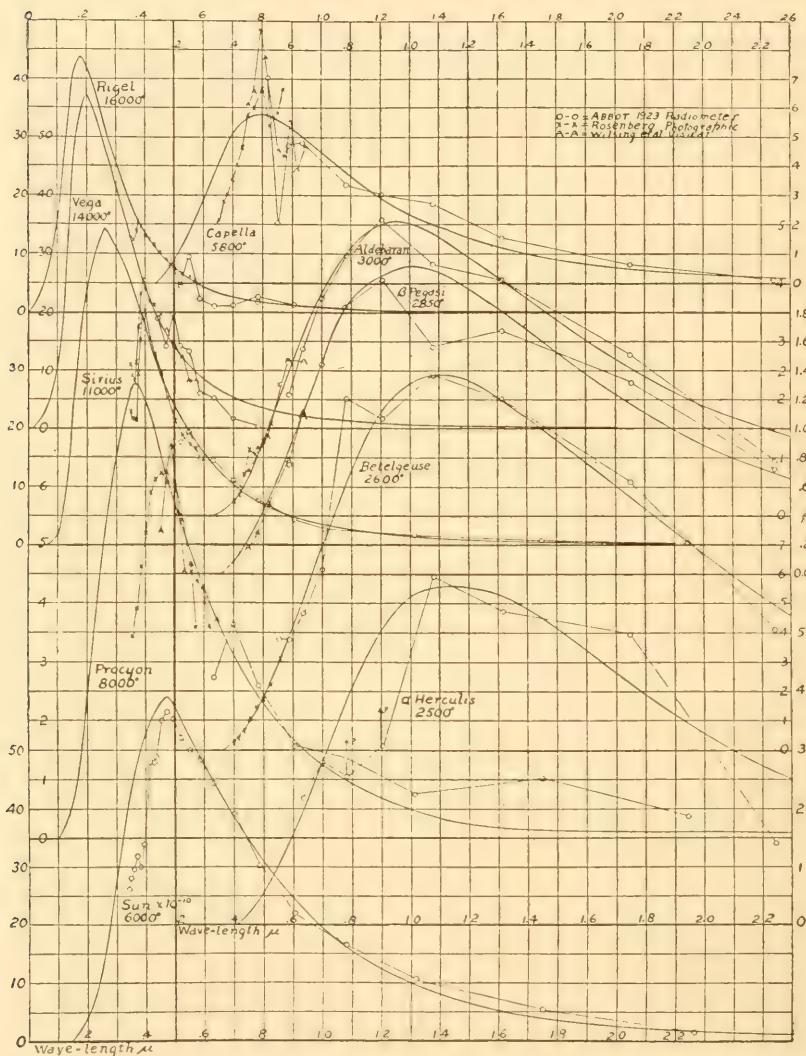
FIG. 39.—Normal energy-spectrum curves and corresponding black-body curves. Various scales of ordinates; two scales of abscissae.

he obtained fairly accurate measurements of the heat of the different colors, and even far into the infra-red. In this way curves were drawn

indicating the spectral distribution in the radiation of blue, white, yellow and red stars, and estimates of their probable temperatures were made. From these results and the results giving the total amounts of heat they send compared to the sun, estimates were possible of the diameters of the stars observed.

A summary of these results follows, in which the diameters he estimated are compared with the values found in other ways by Michelson's interferometry methods, and by Russell from photometry. It is hoped to improve the sensitiveness of the radiometric devices sufficiently to make possible a study of much fainter stars.

STELLAR TEMPERATURES, RADIATION, AND DIAMETERS

Star	Absolute temperature C.	N* Unit=10⁻¹¹	Parallax	Diameter ⊙ = 1†		
				Radiometer	Interferometer	Russell
Sun	6,000°	....	.....	....	....	....
β Orionis ..	16,000	3.20	0″.007	20.	....	28.
α Lyrae	14,000	6.10	0 .130	2.0	....	3.0
α Can. Maj.	11,000	6.60	0 .370	1.2	2.0	....
α Can. Min.	8,000	1.24	0 .315	1.1	....	1.6
α Aurigae..	5,800	2.20	0 .071	13.	....	9.
α Tauri	3,000	2.54	0 .053	70.	39.	....
β Pegasi ...	2,850	1.11	0 .026	94.	82.	....
α Orionis ..	2,600	7.90	0 .017	510.	280.	....
α Herculis..	2,500	3.60	{ 0 .007	900. }	....	230.
			{ 0 .013	480. }		

*N = Ratio of stellar to solar radiation outside earth's atmosphere.
† To express in kilometers, multiply by 1.42×10⁶. To express in miles, multiply by 0.865×10⁶.

ZOOLOGICAL EXPLORATIONS IN WESTERN CHINA

For several years the Rev. David C. Graham, of the West China Mission of the American Baptist Foreign Mission Society, has been collecting natural history material in the vicinity of his station at Suifu, in the province of Szechuen, and sending his specimens to the U. S. National Museum. At times his activities have led him further afield, and last year (1923) he conducted a successful trip to Tatsienlu, a locality several days' journey to the northwest of Suifu.

Tatsienlu is an important spot for naturalists through being the type locality for many species brought to light by earlier travellers. It was visited by the Abbé Armand David about the year 1869, by Prince Henri d'Orleans in 1890, and by A. E. Pratt in the same year, followed in 1894 by a Russian explorer, G. Potanin. Ernest H. Wilson

and W. R. Zappey were there in 1908, the former interested in botany and the latter in zoology. In 1913, a German traveller, Walter Stötzner, made collections in various parts of Szechuen, including Tatsienlu and vicinity. The above incomplete list of visitors who have made this place a collecting ground will suffice to stamp the region as one fairly well known to naturalists. Nevertheless, the locality was all but unrepresented in the U. S. National Museum collections, and the material sent in by Mr. Graham was received with no little gratification.

After finishing his trip to Tatsienlu, Mr. Graham contemplated a visit to Moupin, the scene of some of David's early work and also a type locality of note, but the presence of bandits in that district caused him to look elsewhere for the moment and he decided upon Songpan (or Sungpan), in the northern part of the province, reasoning that a visit to this district would result in the gathering of many species not common to the regions he had already explored. This trip was projected at the end of the year 1923 and began to assume shape in May of the year 1924, when the Smithsonian Institution with the approval of Dr. W. L. Abbott, transferred to him the collecting outfit of the late Charles M. Hoy, who had been operating in the province of Honan.

Songpan was first visited by an Occidental in 1877, when the late Captain W. J. Gill reached it, according to Ernest H. Wilson, who was there on several occasions, the first time in 1903, during his botanical travels in Szechuen. Berezowski spent several months at Songpan in 1894, and Stötzner collected specimens there in 1913. Wilson writes that since Gill's entry into the city " several foreigners have paid visits, and missionaries of Protestant denominations have made abortive attempts to establish stations there."

While Songpan was the objective of Graham's proposed journey, it was not so much the actual city as the general region that attracted his attention. He had heard that good collecting ground existed in its vicinity, hence looked forward to it as a trip worthy of trial. During the latter part of May and early June he made himself familiar with the new outfit and carried out his plans and preparations for the long, rough trip. The distance from Suifu to Songpan in a straight line is probably not much over 240 miles, but by the route travelled would be nearer 400 miles, partly by water, but chiefly by land, and to keep the cost of the trip within his original estimates, Mr. Graham planned to walk over practically all of the overland part of his journey.

Preparations were completed for the trip by the 22d of June, and at daybreak on the morning of the 23d, Mr. Graham and his party, consisting of several Chinese carriers, helpers, skinners, etc., embarked by boat from Suifu. They touched at various minor towns and hamlets by the way, collecting specimens at every opportunity, and reached Kiating, the first place of importance, on the 29th. Frequent and heavy rains fell almost daily, but the party succeeded in registering specimens from point to point throughout the journey. From Kiating to Chengtu Mr. Graham's party had an escort of four soldiers, and beyond Chengtu the escort consisted of double this number, who had neither guns nor swords for defense; yet, withal, the party got through in safety. Chengtu was reached on July 2, after daily stops at small towns and villages. Mowchow, the next place of consequence, was reached on the 9th, the country for some miles on either side of it being semi-arid in nature; apparently for the time they had passed out of the region of heavy rains.

The Graham party arrived at Songpan on July 14, after a strenuous journey of twenty-two days. During his stay at this place, Mr. Graham found the city was devoid of foreigners, and the native officials would not permit him to venture out of its limits except to the east and south.

In a letter dated September 3, 1924, Mr. Graham writes:

The Songpan trip has been taken, and we are safely at Suifu with 50 boxes of specimens, most of which are about ready to be mailed by parcel post.

This has been a harder and rougher trip than the one to Tatsienlu or any other previous trip. It is much harder to secure food and other necessities around Songpan than at Tatsienlu. There were times when we could purchase no fruit, vegetables, eggs, or meat. At Songpan it was impossible to go west or north, where large mammals are found in abundance, so that the only place we could go was east to the Yellow Dragon Gorge. Even there we had to have an escort of six Chinese soldiers and had of course to pay all their expenses.

Continuing, he writes:

The reason we could not go north of Songpan or west of that place was that the Bolotsi aborigines are so savage and so inclined to murder and brigandage that the Chinese can not control them and are afraid of them, and the officials could not protect us in those regions. . . . . Just before we returned from Songpan, the Bolotsis attacked a company of Chinese soldiers, killed several of their number, stole several rifles, and drove the scared and defeated soldiers back to their barracks. I have not heard that the Chinese have dared to go into the Bolotsi country with a punitive expedition.

The catch of mammals is not large. We are very sorry about this. It is due primarily to the fact that the mammal-catching districts around Songpan

were closed to us. Yellow Dragon Gorge was a fine place for birds and insects, but a great festival had just been held there, in which aborigine and Chinese hunters from all directions had joined in the chase, and wood cutters were busy in the woods cutting timber for the new temples that are being constructed. The mammals had been scared away.

In addition to the material collected on the Songpan trip, Mr. Graham had native collectors at work in other districts, about whose activities he writes:

This year's catch is bigger than that of last year. There are 50 boxes of specimens on hand, and I expect to send them off by parcel post as early as possible. Besides the 50 boxes just mentioned, there is the entire catch of the netter Ho for at least three months, who has been collecting about Beh Luh Din, Chengtu, and Kuanshien during the summer, and specimens now being secured by two collectors on Mt. Omei, one at Shin Kai Si and one on the higher altitudes.

The material obtained on the Songpan trip included about 5,000 insects, of which the two-winged flies and butterflies and moths constituted an important element, many of them being either new to the Museum or new to science. The birds, 558 in number, were received at a late date, and have not been fully examined, though to date about a dozen species new to the Museum have been detected.

About 250 mollusks and a lesser number of mammals, fishes, reptiles and batrachians, earthworms, plants, etc., comprise the remainder of the shipment.

VISIT OF MR. GERRIT S. MILLER, JR., TO THE LESSER ANTILLES

During February and March, 1924, I visited the Lesser Antilles, more for the purposes of vacation and of getting a personal impression of the islands than with any plan for definite research. Two weeks were spent on Barbados and a month on Grenada; while each of the principal islands was visited for a few hours during the southward and return voyages. Some miscellaneous collections were made, chiefly of ferns, cacti, and lizards.

Much detailed work in zoology and botany remains to be done on the islands of the Lesser Antillean chain. As a striking illustration of this fact, it may be mentioned that, in a group of plants so conspicuous as the cacti, and so well monographed as these have recently been in the elaborate work of Dr. N. L. Britton and Dr. J. N. Rose, nine species (7 genera) were found growing wild on Grenada, from which island these authors had actually examined only two. One of the common Grenadan cacti was described in 1837, but had remained

FIG. 40.—Market, St. Kitts—mostly vegetables and fruit. The Island of Nevis appears dimly in the background.

FIG. 41.—Market, St. Vincent—whale blubber.

FIG. 42.—Market, Barbados—pottery.

Fig. 43.—Harbor of Charlotte Amalie, St. Thomas.

Fig. 44.—Basse Terre, St. Kitts. Lighters coming out to the steamer. At only two islands (St. Thomas and St. Lucia) is the water of the harbors deep enough to permit large vessels to dock.

Fig. 45.—Ruined sugar mill, Montserrat. Ruined windmills—abandoned in favor of modern machinery—are as characteristic of the Lesser Antillean landscape as the old watch towers are of that of the Mediterranean coast of Europe.

Fig. 47.—Street near botanical garden, Roseau, Dominica.
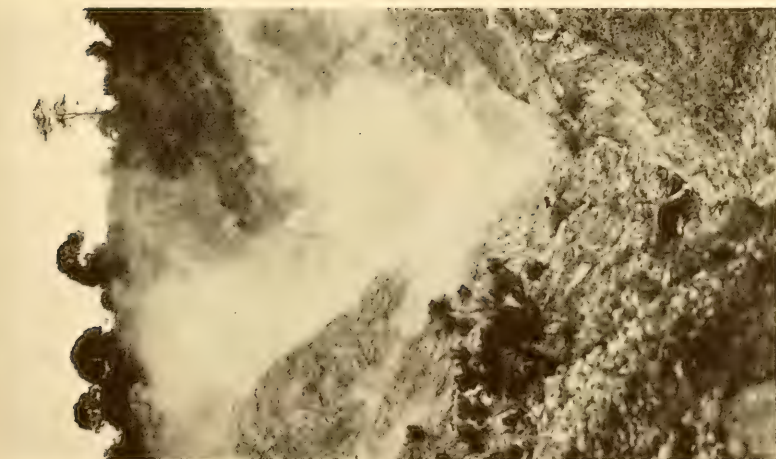
Fig. 46.—Sulphur vent, Montserrat, near left base of the mountain shown in fig. 45. This vent is now increasing its area, and killing many trees, which had grown to large size near it.

Fig. 48.—Pointe-a-Pitre, Guadeloupe. On account of quarantine regulations, no closer approach to the town was allowed during the winter of 1923-24.

Fig. 49.—Bridgetown, Barbados.

FIG. 50.—Avenue of palms and Casuarina, Barbados. Young sugar cane in foreground.

FIG. 51.—Negro fisherman searching for crabs, eels and rock inhabiting fish at Atlantis, windward side of Barbados. The peculiar undercutting of the rocks is often seen along this part of the coast.

FIG. 52.—Cactus (*Cereus grenadensis*) on Glover's Island, off south coast of Grenada. Unlike *Cereus hexagonus,* this species appears to branch naturally.

Fig. 54.—Cactus (*Acanthocereus pentag-onus*) on rocky shore of Glover's Island, off south coast of Grenada.
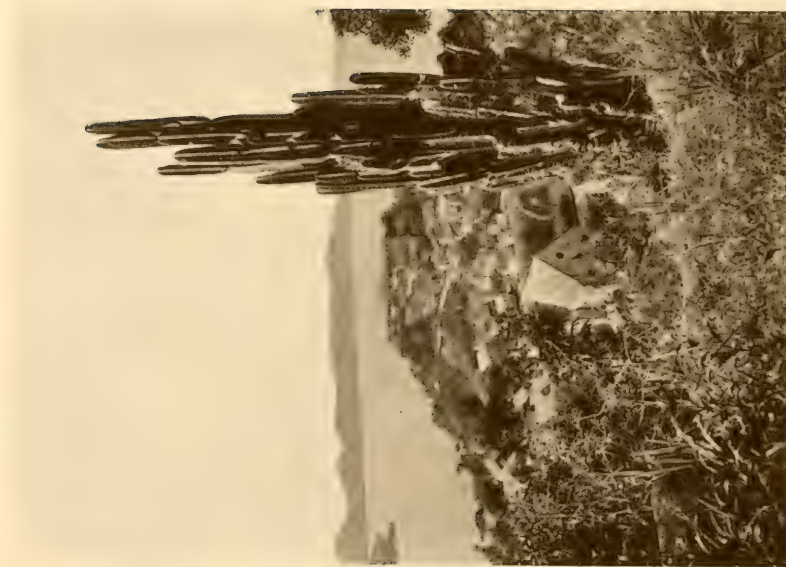
Fig. 53.—Cactus (*Cereus hexagonus*) on hill above St. George, Grenada. The branching of this plant seems to be chiefly due to injuries. When growing in protected situations among trees it forms simple columns 30 feet high.

" lost " until, under the guidance of Dr. J. N. Rose, I " rediscovered " it ; yet the plant flourishes at the roadside within a few hundred yards of the fine botanical garden in the suburbs of Saint George. For the convenience of anyone who might be interested in doing some field-work on these Islands, attention may be called to the ease with which they can be reached. The boats of the Quebec Steamship Company maintain a service from New York to Barbados, touching at the islands of St. Thomas, St. Croix, St. Kitts, Antigua, Guadeloupe, Dominica, Martinique and St. Lucia, and remaining at each for a period which depends on the quantity of cargo to be handled, but which is usually from three to ten hours. As the islands are small and the roads on most of them are good, there is usually time to get a fair general idea of topography, forests and cultivation during the vessel's call, particularly when it is remembered that points of special interest can be seen again on the return voyage. From Bar-bados the passage to St. Vincent and Grenada is made by the Royal Mail boats plying between St. John, New Brunswick, and Demarara, British Guiana, by way of Bermuda, the Lesser Antilles and Trinidad. There is also a line directly from New York to Grenada and Trinidad, but this gives no opportunity to see other islands. On the return voyage inconvenience may be experienced in obtaining passage owing to the number of " round trippers " with whom the boats are some-times crowded ; and for the same cause travel between neighboring islands is not always easy.

The appended photographs show characteristic scenes.

GERRIT S. MILLER, JR.

EXPERIMENTS IN HEREDITY AT THE TORTUGAS

In continuation of the heredity experiments in the Tortugas con-ducted under the joint auspices of the Smithsonian and Carnegie Institutions, Dr. Paul Bartsch visited Cuba from May 27 to May 30 this year, in order to add a spirally striated Cerion element to the Cerion colonies established at the Tortugas. Thanks to the good offices of Dr. Carlos de la Torre, of the University of Havana, he was able to secure a sufficient series of a strongly spirally striated new spe-cies of Cerion belonging to the *Cerion johnsoni* group at Mariel, where also a large number of *Cerion sculptum*, likewise, though less strongly spirally striated, were gathered. In addition to these, *Cerion mummia* from Marianao and *Cerion chrysalis* from Cabanas Fort and *Cerion tridentata* from Rincon de Guanabon were collected and planted at the Tortugas. The last is peculiar on account of the internal lamel-lation of the aperture, thus adding another element to our experiments.

On June 1 a visit was paid to the hybrid Cerion colony on New-found Harbor Key. This was found to be in a flourishing condition and 100 specimens were taken to Washington for record and dissection. From June 2 to June 15 was spent at the Tortugas where the various Cerion colonies which have been established there were studied and new ones added. All the colonies were found to be doing well, excepting that of *Cerion uva* from Curaçoa, which is on the verge of extinction.

FIG. 55.—Four of the six island groups.

We gathered a number of *F2* Florida-grown specimens of *Cerion crassilabre*, which show no measurable differences from those of the check series of the *F1* Florida-grown generation, thus again confirming our finding with the other races of transplanted Cerions, that changed environmental factors have no appreciable influence upon the *F1* and *F2* generations of the transplanted material.

A large series of offsprings of the mixed colony of *Cerion casablancae* and *Cerion viaregis* (Colony I) were gathered and taken to Washington to be carefully studied for a possible cross.

New Colonies of Cerions Established This Year

500 *Cerion mummia* from the point at Miramar, Cuba.
500 *Cerion chrysalis* from near Cabanas Fort, Cuba.
500 *Cerion sculptum* from near the lighthouse at Mariel, Cuba.
125 *Cerion* new species, young specimens from a little east of the point at Mariel, Cuba.
500 *Cerion tridentata* from Rincon de Guanabon.

These were planted on the west and north side of the parapet at Fort Jefferson on Garden Key, each duly marked with a stake and tag.

Our failure in the past to grow Cerions in cages at the Tortugas caused us to try isolating them on little islands this year. Mr. Mills inclosed four 6 x 6 ft. areas with a concrete trench, a cross-section
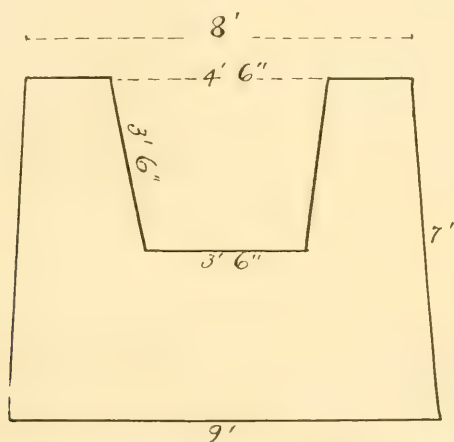
Fig. 56.—Cross-section of concrete trenches.

of the construction of which is shown in the accompanying diagram (fig. 56). Two additional areas of the same size were subdivided by a similar median septum which yielded four almost 3 x 3 ft. islets. The simple trenches require each some nine pails of water and the compound correspondingly more. Arrangements have been made with Mr. Charles Johnson, keeper of the Tortugas lighthouse, to keep these trenches filled with water. Evaporation at the Tortugas is great and it will be necessary to replenish the loss of water almost daily. For this purpose a pump has been installed in the middle of the battery of islands which will make this a comparatively easy daily task.

The inclosed areas have been planted each with a Hymenocallis plant and a few such grasses as are favored by Cerions, likewise a few added fragments of coconut pediole fibers; in other words, all things

FIG. 57.—Good's pompano (*Trachinotus goodi* Jordan and Evermann).

FIG. 58.—A group of Grey Snappers (*Neomænis griseus* L.) swimming in
an aisle between massive coral heads.

favored for attachment by Cerions. These islands are placed south of the laboratory and east of the men's quarters. They have been stocked with:

1. 25 *Cerion incanum* and 25 *Cerion* new species
2. 25 *Cerion incanum* and 25 *Cerion chrysalis*
3. 25 *Cerion incanum* and 25 *Cerion mummia*
4. 25 *Cerion incanum* and 25 *Cerion tridentata*
5 and 6. In each compartment a two-thirds grown individual of *Cerion incanum* and *Cerion viaregis*.

On June 15, during the return trip to Key West, Man and Boy Keys were visited. The Boy Key colony has in part survived the burning of last year, but that on Man Key has again been burned over and it is questionable if any living thing is left in it.

Thanks to the authorities of the United States Bureau of Fisheries, some plantings were made within the compound of the Fisheries station at Key West where our colonies will be safe from burnings. Two colonies were established here on the opposite extremities of the seaside leg of the grounds. They consist of 500 specimens each of *Cerion viaregis* and *Cerion incanum,* and 500 each of *Cerion tridentatum* and *Cerion incanum,* respectively.

In addition to the work done at the various stations on the Florida Keys and Cuba, twenty of the hybrid Cerions from the Newfound Harbor colony have been dissected at the National Museum by Miss Mary E. Quick, under the direction of Dr. Bartsch. These show most remarkable changes in anatomic character. It is planned to make a greater number of dissections of these hybrid Cerions in order to determine the range of changes produced by hybridization.

While at the Tortugas, Dr. Bartsch exposed 1,200 feet of moving picture film with his undersea camera, photographing denizens of the coral reef. He took the precaution this year to place the camera upon a tripod, which has eliminated the seasickness-producing effects obtained during similar efforts last year when the camera was held freely in the hands while working in a rather rough sea. The negatives since developed are quite satisfactory.

As in previous years a full record of the birds seen from day to day was kept and added to the list recorded in the past. This has yielded so far not only a large series of notes on the avian population of the Florida Keys and the breeding habits of local forms, but much information on bird migration.

INSECT COLLECTING EXPEDITION IN THE PACIFIC COAST
REGION

On May 31, 1924, Dr. J. M. Aldrich, associate curator of the
division of insects, U. S. National Museum, left Washington on a
western trip for the purpose of examining type material of insects in
certain museums and collecting the two-winged flies in localities of
especial interest in the Pacific Coast region.

The first official work was done at the University of Kansas, where
some types of muscoid flies were examined. Next, a stop for col-
lecting was made at Redlands, California, and two days were spent

Fig. 59.—Coast of Oregon, near California line.

in the San Bernardino Mountains with Dr. Frank R. Cole. This
mountain range is somewhat isolated in position, but includes in its
fauna some of the northern species of flies as well as some known
from Mexico. An entirely different fauna is that of the lower San
Joaquin Valley where the next stop was made at the town of Newman.
In this vicinity the dry weather had made the collecting very poor,
except along the banks of the San Joaquin River; but here some
insects of unusual interest were obtained, including one genus new
to the National Museum.

Two days were spent in the Academy of Natural Sciences in San
Francisco, examining types and assisting to some extent in determin-
ing material for the museum A brief visit to Stanford University
permitted the examination of some interesting type material of para-
sitic flies occurring on birds and bats.

From Oakland, California, the trip was made by automobile to
Eureka and on up the coast into Oregon as far as Marshfield. Along
this route the extremely dry season made the collecting very poor
except in the vicinity of Marshfield, where the climate is compara-
tively humid and the collecting was much better. Two days were
spent here with very good results. At Corvallis, Oregon, some type
material was examined in the collection of the Agricultural College.

In the vicinity of Spokane, Washington, considerable collecting was
done for two or three days, resulting in additions of some value but
not of exceptional rarity.

Fig. 60.—Coast of Oregon, near California line.

Near Moscow, Idaho, the mountain locally known as Mount Mos-
cow was visited on several days and some important material obtained.
This mountain is the type locality for a considerable number of new
species of insects. At Kendrick, Idaho, the greatest rarity of the
trip was discovered, about 20 specimens of a fly which was originally
described in 1877 from streams in Marin County, California.

Two days were spent in collecting at Summit, Montana, and at the
Glacier National Park railroad station, a region from which very
few flies had previously been obtained for the National Museum.

The illustrations shown (figs. 59, 60) are from photographs taken
along the Pacific Coast in southern Oregon, where a very good high-
way winds in and out of the forests, frequently following the bluffs
along the ocean.

BOTANICAL EXPLORATION IN PANAMA AND COSTA RICA

With the cooperation of the government of the Panama Canal, botanical field-work was undertaken in 1923 in the region of the Zone by Mr. Paul C. Standley, associate curator of the division of plants, U. S. National Museum, with the object of obtaining collections and data for a report upon the plant life, which it is planned to publish in the near future. Part of November, December, and most of January were spent in botanical exploration in and near the Zone. Nearly all parts of this area were visited, and 7,000 numbers of plants were obtained, represented by about twice as many specimens. These collections are now being studied and have been found to contain a number of species new to science, besides many not collected previously in the area.

The vegetation of the Zone is typical of that existing in Central America at low elevations, but it is here possible to study in close proximity the floras of the Atlantic and Pacific slopes, these floras being sharply differentiated in Central America because of differences in the climates of the two watersheds. The Pacific slope has well defined wet and dry seasons; on the Atlantic slope there is usually plentiful moisture throughout the year.

Although the original vegetation of the Isthmus of Panama has been greatly modified in many places because of long occupation by man, and especially because of operations incident to the construction and management of the Canal, there remain near the Canal extensive areas of virgin forest whose animal and plant life is of great interest. Advantage has been taken of this fact to establish recently a station for tropical scientific research on Barro Colorado Island in Gatún Lake, the island having been set aside for the purpose by the Governor of the Canal. Upon this island, largely as a result of the energy and enthusiasm of Mr. James Zetek, there has been constructed this year a laboratory building with accommodations for students, and trails have been cut to make the virgin forest, which covers several hundred acres, available for study.

The most striking botanical feature of the Canal Zone is doubtless the orchid garden formed by Mr. C. W. Powell of Balboa. In this collection Mr. Powell has assembled orchid plants from many parts of Panama, and he has in cultivation nearly all the species known to occur in the Republic. During the last ten years he has found over 300 species, about three times as many as were known previously from Panama, and many of them have proved to be forms unknown to orchid students.

Fig. 62.—*Cattleya dowiana*, native of Costa Rica, probably the finest orchid of Central America. Sepals and petals pale buff; lip deep crimson with golden veins
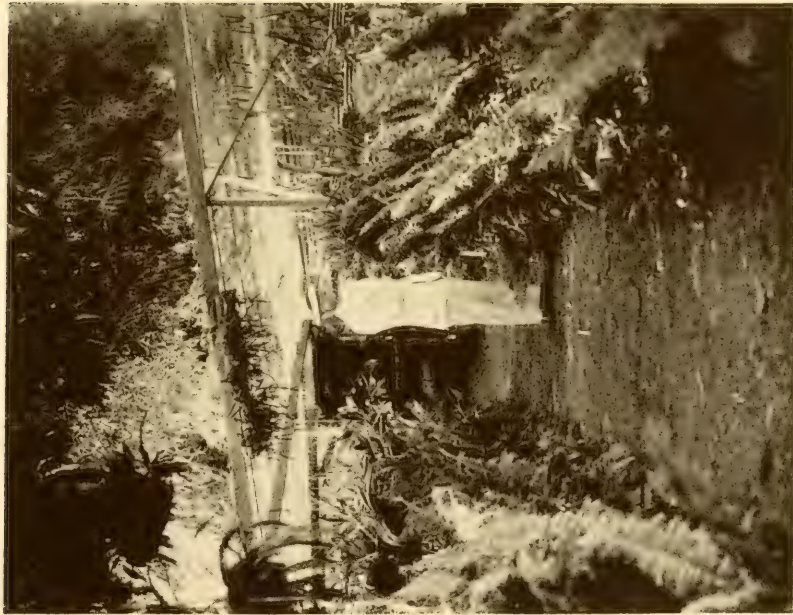
Fig. 61.—Orchid garden of Mr. C. W. Powell, Balboa, Canal Zone.

Fig. 63.—A patio of a Costa Rican home. Nearly all Central American houses are built about a courtyard, which is beautifully decorated with orchids, ferns, and other plants, making a delightful place in which to live. The tile floors of the corridors are frequently very elaborate and handsome. (Photograph by M. Gómez Miralles.)

FIG. 64.—*Cattleya skinneri* in Costa Rica, one of the handsomest of Central Amer can orchids. Flowers purple. (Photograph by M. Gómez Miralles.)
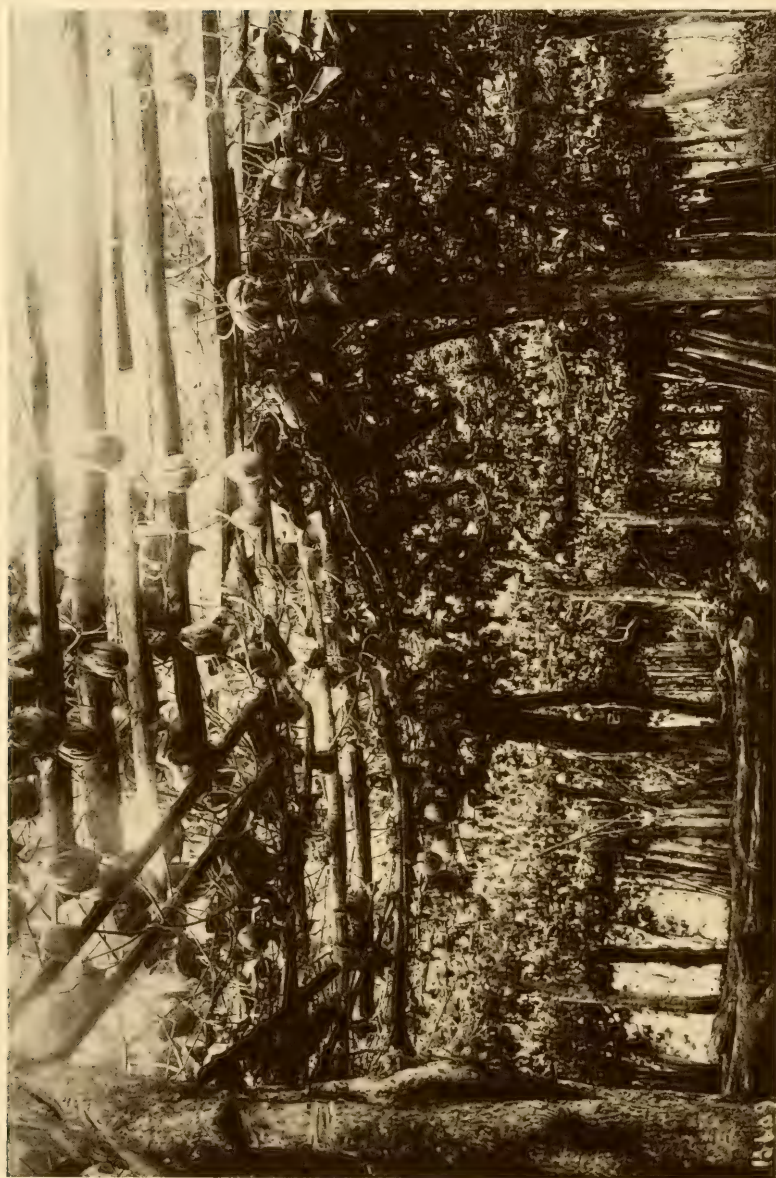
Fig. 65.—Method of growing the chayote (*Sechium edule*) in Costa Rica. The chayote, a relative of the cucumber, which it somewhat resembles, is one of the popular vegetables of tropical America. (Photograph by M. Gómez Miralles).

FIG. 66.—View along the Reventazon River, Atlantic lowlands of Costa Rica. The tall cane at the right is much used in the construction of houses. (Photograph by M. Gómez Miralles.)

At the end of January, Mr. Standley proceeded to Costa Rica, remaining there until the middle of April, when he returned to Washington. Costa Rica is botanically the richest part of North America. In the highlands, where the climate is temperate rather than tropical and where there is a heavy rainfall, the vegetation is extraordinarily luxuriant, and the variety of plants bewildering. Although large collections already have been made in Costa Rica, it will require many years of intensive exploration to gain an adequate knowledge of the plant life.

Mr. Standley's collection consists of 8,000 numbers of plants, many of which will doubtless prove to be new. Special attention was given to the orchids, of which about 1,500 numbers were obtained. These are now being studied by Mr. Oakes Ames, through whose interest the work in Costa Rica was undertaken. Of orchids Costa Rica possesses probably a larger number of species than any other portion of the American tropics of equal extent. Over 1,000 species have been reported from this small Republic, and it is certain that many more await discovery. While most Costa Rican orchids, like those of other countries, have inconspicuous flowers, some, such as the Cattleyas, are of unsurpassed beauty.

Visits were made to the Volcano of Poás, celebrated for its great crater, which contains a lake that erupts frequently; to the Volcano of Turrialba, whose forests are noted for their wealth of ferns; and to many other rich localities in the central highlands.

A short visit to the comparatively arid Pacific coast proved that the flora of this part of Costa Rica is relatively meager and uninteresting. Several visits were made to the wet lowland forests of the Atlantic watershed, where the vegetation is even more luxuriant than in the mountains and the species are almost equally numerous. Little is known of the plants of the Atlantic lowlands of Central America, although it is probable that no other region will better reward exploration.

BOTANICAL WORK IN SOUTHEASTERN NEW MEXICO

During part of August, 1924, Mr. Standley was detailed for field-work as a member of the Carlsbad Cavern Expedition of the National Geographic Society. This expedition, under the direction of Dr. Willis T. Lee, was engaged this year in a detailed survey of the Carlsbad Cavern, recently set aside as a national monument, and of its surroundings. The cavern is noteworthy because of its large size and lavish decorations, and is one of the most notable of the

many remarkable natural features of the State of New Mexico. Mr. Standley made a study of the plants of the plains and hills near the cavern, an area possessing a great variety of cactuses and other characteristic desert plants of the Southwest. Visits were made also to the canyons of the near-by Guadalupe Mountains. This range, partly in New Mexico and partly in Texas, has at its southern end Signal Peak, the highest point in the latter State, about which it has been proposed to establish a State park. The Guadalupe Mountains are comparatively unknown botanically, and numerous species were found that had not been collected previously in New Mexico. One of the interesting features of the vegetation of these mountains is the profusion of the Venus-hair fern (*Adiantum capillus-veneris*), a species rare in the Southwest but here abundant everywhere along the small streams.

After completion of the field-work in the vicinity of the cavern, a trip by automobile was made to El Paso, Texas, passing the southern end of the Guadalupes. From El Paso the route was followed to Las Cruces, New Mexico, and thence over the picturesque Organ Mountains and past the White Sands, a vast expanse of gypsum sand, almost pure white, resembling great drifts of snow. The White Mountains also were visited, and the road was followed to Roswell and Carlsbad, thus making it possible in a short time to gain a general impression of the varied types of vegetation covering a large area of characteristic desert and mountain country of southern New Mexico.

BOTANICAL EXPEDITION TO THE CENTRAL ANDES

During the summer and fall of 1923, Dr. A. S. Hitchcock, botanist in charge of systematic agrostology, Bureau of Plant Industry, Department of Agriculture, and custodian of the section of grasses of the U. S. National Museum, visited Ecuador, Peru, and Bolivia for the purpose of studying and collecting the grasses. He left New York May 25 and arrived at Guayaquil June 16, making a short stop at Port au Prince, Haiti, and at Buenaventura, Colombia, and a stay of several days at Panama.

The work in Ecuador was done in cooperation with the New York Botanical Garden and the Gray Herbarium of Harvard University, and these institutions shared in the specimens obtained. Therefore in this country the collections included all families of flowering plants. Several localities on the coastal plain were visited, after which collections were made in the vicinity of Huigra, a town on the railroad

at 4,000 feet elevation. Headquarters was then transferred to Quito, the capital, at 9,500 feet elevation. The only important railroad in Ecuador runs from Guayaquil to Quito, crossing the coastal plain for about 100 kilometers and then ascending through one of the valleys to the Sierra or central plateau over a pass about 10,000 feet. The train

FIG. 67.—Angel's trumpet (*Datura arborea*), a small tree about 8 feet tall with white flowers about 8 inches long. A native plant frequently cultivated for ornament in the Andes.

takes two days to make the trip, stopping overnight at Riobamba. Quito is rather cold, but Riobamba and Ambato have a very salubrious climate.

An overland trip was made from Quito to Tulcán on the Colombian border, occupying about a week. Another trip taking about three

Fig. 68.—A country road near Ambato. A species of Agave is commonly used as a hedge plant. Dr. Hitchcock's horse stands in the foreground with a McClellan army saddle taken from Washington. The uncomfortable native saddles are used with heavy pads of sheep's wool.

Fig. 69.—A street of Lima, a fine, modern city, in which the architecture, as in all South American cities, is essentially that of continental Europe

weeks was made from Guayaquil to Santa Rosa by boat and by mule to Portovelo, a gold mine in charge of Americans, to Loja, the southernmost town of importance in Ecuador, and then north through Cuenca, the third city in size, and on to Huigra. A short journey of four days was made into the Oriente from Ambato to Baños and on to Cashurco near Mera. The last collecting was done on the great peak of Chimborazo, ascending to snow line at about 16,000 feet.

Leaving Guayaquil October 11, Callao was reached October 17. In Peru two chief regions were visited, the first being the central plateau east of Lima. A railroad runs from Lima to Oroya (12,000 feet) and north to Cerro de Pasco (14,300 feet). This road is a

FIG. 70.—Atocsaico Ranch, near Junín, Central Peru. The ranch is on the great central plateau at about 13,000 feet and is mainly devoted to sheep-raising. The region lies above tree line, but provides excellent grazing.

marvelous piece of engineering, going over a pass at nearly 16,000 feet, and provided with numerous tunnels, bridges, and switchbacks. A side trip was made down the east side to Colonia Perené, a coffee plantation at 2,000 feet, and another to the Atocsaico Ranch, near Junín, at 13,000 feet, where there is excellent grazing the year around for 35,000 sheep and 1,100 cattle. Cerro de Pasco, on account of the altitude, is a cold bleak place. Here grows the curious moss grass (*Aciachne pulvinata*), covering entire hills with hard compact rounded tussocks. From here a trip was made to La Quinhua, a gold mine at a lower altitude, and another to Goyllarisquisca, a coal mine, also at a somewhat lower altitude, where the collecting was very good.

Fig. 71.—A quarry from which the Incas obtained stones for the great fortress near Cuzco.

Fig. 72.—A portion of a wall in the great Inca fortress near Cuzco. The stones are fitted with great exactness, but without mortar. A drainage opening is shown in center. The corner stones are rounded and the wall slopes a little. The Incas had no beasts of burden (the llama will carry 75 pounds, but will not pull in harness) and no metal tools. Some of the large stones weigh many tons.

5

The second region visited in Peru was reached by the Southern Railway from Mollendo on the coast. The first day takes one up to Arequipa at 7,500 feet, where a few days were spent. The second day takes one to Juliaca, and the third to Cuzco. A few days were spent at a new Government experiment station at Chuquibambilla (13,000 feet), north of Juliaca. This station is well-equipped and is devoting its attention chiefly to sheep-raising.

From Cuzco (11,500 feet) a trip was made down the valley northward to Ollantaytambo over a new railroad which ultimately will reach Santa Ana, head of navigation on the Urubamba river. At

FIG. 73.—Mules loaded with coca leaves at Ollantaytambo, Peru, on the way to Cuzco from the lower altitudes. Coca leaves are chewed with a paste of ashes by the Indian men to prevent fatigue. The leaves are largely exported for the production of cocaine. The growing of the coca bush is an important industry of the montañas of Peru and Bolivia.

Ollantaytambo and at Cuzco there are fine examples of Inca architecture, now in ruins, but showing the remarkable stone walls in which the irregular stones are fitted with great accuracy but without mortar.

On going to Bolivia from Cuzco the traveler returns on the Southern Railway to Juliaca, there takes a branch line to Puno on Lake Titicaca, crosses the lake by night on a comfortable little steamer to Guaqui, and then goes by rail to La Paz.

Lake Titicaca, the largest lake in South America and the highest for its size in the world, is 130 miles long, 3,200 square miles in area, and as much as 900 feet deep. The railroad from Guaqui

passes over a high plain, gradually ascends from 12,500 to 13,500 feet, then abruptly descends into a bowl or valley to La Paz at 12,000 feet. It is a very striking experience to come suddenly to the edge of the plain and look down 1,500 feet on the beautiful city below.

From La Paz a four-day journey by mule was made to the great mountain mass, Illimani, about 25 miles nearly east of the city. This snow-capped mountain is a beautiful sight from La Paz and dominates the landscape much as do Rainer and Shasta in this country. The peak is about 22,000 feet in altitude (6,619 meters) but was ascended only to snowline, about 16,000 feet.

A second journey from La Paz was to the Yungas, a region in the montañas (forested region) north of the city but on the Amazon slope of the Cordillera. The trip was made in company with Dr. Otto Buchtien, the well-known German botanist, long resident in Bolivia, who has done so much work on the plants of that country. A railroad takes one over a pass at about 15,000 feet to Pongo (about 12,000 feet), the present terminus of the road which is under construction into the Yungas. Through the courtesy of the director of the railroad, mules were furnished for a week's travel down through the provinces of Nor-Yungas and Sur-Yungas to Chulumani and Coroico. This region is the center of the coca industry of Bolivia. The leaves of the coca shrub (not to be confused with cacao or chocolate tree, nor with the coconut palm) are much used by the Indians as a stimulant. The leaves are mixed with a paste of ashes and chewed. The leaves also form an important article of export as they are the source of the drug cocaine.

After leaving La Paz a journey was made to Cochabamba, a rich agricultural district toward the east on the slope from the main Bolivian plateau. The last expedition was made through the aid of the Ulen Contracting Corporation which is constructing a railroad from Uyuni in southern Bolivia on the main line from La Paz to Antofagasta, Chile, to Villazon on the Argentine border where it will join the Argentine system. The road is now in use as far as Atocha and ultimately will complete the line from La Paz to Buenos Aires. Ten days were spent on a mule-back round trip from Atocha to La Quiaca, the northernmost town in Argentina.

The return home was made from Antofagasta, arriving in New York February 16, 1924.

The region visited consists topographically and climatically of three main divisions. There is a coastal plain mostly not more than 100 miles in width extending all along the coast. In northern Ecuador

Fig. 74.—A glacier on Illimani, altitude about 16,000 feet. Illimani, lying about 25 miles nearly east of La Paz, is a dominating feature of the landscape like our Rainier or Shasta. This and Sorata or Illampu, 40 miles to the north of La Paz, are both nearly 22,000 feet (6,619 and 6,645 meters).

FIG. 75.—In the heart of the Andes or Cordillera Real. On the way to the Yungas, a region on the Amazon slope north of La Paz. This is in the montaña (wooded mountain slopes) and is the center of the coca industry of Bolivia. Altitude about 5,000 feet.

this plain has an abundant rainfall but becomes drier to the south and in Peru is a desert. In Ecuador the chief crops are sugar and cacao. In Peru the agriculture is confined to the valleys that can be irrigated from the mountain streams. Here the crops are sugar, cotton, grain, and alfalfa. The temperature of the coastal plain is modified by the Humboldt current which sweeps up from the cold Antarctic regions and the coastal cities of Peru are much cooler than those of the Atlantic coast in the same latitude.

The central part of Ecuador and Peru is occupied by the great Andes mountain system, the Cordillera. In a general way the system

Fig. 76.—A herd of llamas at Atocha, southern Bolivia. The Bolivian plateau increases in aridity southward. The vegetation of the mountains in the background of the scene is very sparse. The foreground is a river bed that is dry, except after the infrequent hard rains.

consists of two chains with a plateau between. In Ecuador the plateau is divided into several valleys by cross ridges. In the valleys at altitudes from 8,000 to 9,500 feet lie the chief cities, such as Tulcán, Ibarra, Quito, Ambato, Riobamba, and Cuenca. In Peru the plateau is at a greater altitude. South of Cuzco (11,500 feet) it broadens into a wide area embracing all western Bolivia, the plateau being mostly 12,000 to 13,000 feet elevation for 400 miles and more than 100 miles wide. Most of the region above 12,000 feet is devoid of trees and the plain increases in aridity southward. The southwestern part of Bolivia is a desert. The plains and slopes above tree line in Ecuador are called páramos and the region is called the Sierra. They are

subject to cold winds which make travelling uncomfortable. In Peru the treeless plateaus are called punas. Many mountain ranges rise above the plateau and snow-capped peaks are numerous. The best known peaks in Ecuador are Chimborazo and Cotopaxi, more than 20,000 feet in altitude. The height and massiveness of the mountain system in central Peru is indicated by the altitude of the pass on the railroad from Lima to Oroya in the central plateau mentioned above.

In Peru and Bolivia there is little in the way of crop production on the puna, but where there is sufficient rainfall the stock-raising industry flourishes. The grazing on the puna of Peru is in the main excellent and large numbers of sheep are raised. In the valleys falling from the plateau agriculture at once begins and crops of beans (habas, the broad bean of Europe) and barley are first seen; somewhat lower are found alfalfa, corn, potatoes, and wheat.

The third primary region is the montaña, a name applied to the wet forested slopes of the Andes on the east. In Ecuador the slope is abrupt on the eastern chain of the Cordillera and soon passes into the Oriente or great rain forest of the Amazon valley. In a general way this montaña region extends through eastern Peru to the Yungas of Bolivia. Beyond that it merges into the Chaco of eastern Bolivia, which is a drier region of scant forest and grassy plains.

The botanical results of the trip have been very satisfactory. A large collection of grasses was made, which will form the basis of an account of the grass flora of the three countries visited. Already several new species have been described from the general collections made in Ecuador.

ARCHEOLOGICAL EXPEDITION TO CHINA

During the winter of 1923-1924, the Expedition sent to China under the joint auspices of the Freer Gallery of Art and the Museum of Fine Arts, Boston, carried on successful investigations at I Chou, in the province of Chihli, and at several localities in the province of Shensi. I Chou is built on the site of an ancient city, perhaps that of Yen Ching, and while there Mr. Carl Whiting Bishop, in charge of the expedition, traced portions of old earthen walls of considerable size, lying to the southwest of the present city. To the east of I Chou, groups of many large, uncovered mounds rise from the flat plains; these were inspected as were also some of the many potsherds and fragments of tile and pottery found on the surfaces of the mounds themselves. Later, Mr. Bishop made a survey of the locality by

FIG. 77.—General view of the Wang Fên Wa mound, looking southeast.

FIG. 78.—Pottery stove retaining traces of glaze; purchased from looters of the Wang Fên Wa tomb, and said to have been found there.

FIG. 79.—Pair of vases purchased in Yü-ho Chên; said to have come from tomb between Wang Fên Wa and the Hsiung Chia T'ai-tzŭ.

aeroplane, in order to determine more accurately the extent and general plan of the ancient site.

In Shensi, the members of the field staff visited the Western Han (206 B. C.–A. D. 25) capital of Ch'ang-an, securing sufficient data

Fig. 80.—Brick cist in which pottery was found; pottery *in situ*. Wang Fên Wa tomb.

while there to make a fair reconstruction of the ancient city. In the same province they inspected also, two large mounds of the usual truncated pyramidal form, ascribed to early Han emperors; the supposed tomb of the emperor Ch'in Shih Huang-ti (221-210 B. C.), and the tombs of the famous emperor Han Wu Ti (140-87 B. C.)

and his general Ho Ch'ü-ping. The tomb of Han Wu Ti is an unusu-
ally large one, measuring 278 yards at its base and presents oppor-
tunities of great archeological interest, as does also that of General
Ho Ch'ü-ping, where Mr. Bishop saw not only the well-known stone
figure of a horse trampling on a recumbent warrior, but examined
also several other partially exposed stone sculptures of the early
Han period. Photographs, and scale plans of several of the tombs
and temples in this vicinity were made.

The first actual excavation work conducted by the Expedition, was
begun in the spring of this year at Yü-ho Chên, about 17 miles west
of Hsin-yang Chou, in the province of Honan. This specific under-
taking has an added significance archeologically, in that it is the
first work of the kind to be conducted in China by any foreign govern-
ment in cooperation with the Chinese authorities. At Yü-ho Chên,
two tombs of the Han dynasty (206 B. C.–A. D. 221), were exca-
vated ; the work revealed interesting data on ancient tomb construction
and brought to light Chinese cultural objects dating from prehistoric
times to the Han period. Specimens in metal, stone and pottery were
found in the tombs ; chariot-fittings, mirrors and arrow-points of
bronze ; one or two gold rings ; cast-iron implements ; a stone axe
and parts of stone doors and lintels ; a jade chisel ; slate arrow-heads,
and a number of pieces of ancient pottery—some intact, some frag-
mentary—among them a kind of glazed pottery which, if it be of
Han production, is a type hitherto scarcely known to us.

In August, the Yü-ho Chên finds were exhibited for one day,
under Mr. Bishop's direction, at the Historical Museum in Peking ;
between 5,000 and 6,000 visitors attended the exhibit.

In the early autumn Mr. Bishop, together with Dr. Barbour, pro-
fessor of geology at Peking University, and Dr. Tegengren, a
Swedish mining geologist, examined a mound at Peitaiho, on the
gulf of Chihli, which discloses evidences of what Mr. Bishop believes
may be a Han dynasty naval base or fortress ; one of three which
are said to have been built at that time, and of which two only have
been located.

A satisfactory report on the purchases made in China during the
past year cannot be prepared at this time, for, until a more detailed
examination of the objects shall have been made, definite information
with regard to age, provenance and type will not be possible. The
purchases include Buddhist stone sculptures, Chinese pottery and
bronzes, and, among the last named, a collection which we believe has
come from Shou Chou, the last capital of the Kingdom of Ch'u, which
was destroyed in 223 B. C.

Fig. 81.—Looking south from rear of tomb at the Wang Fên Wa, showing portions of front walls, stone door-sills, and, above, brick cist in which pottery was found.

Fig. 82.—Bronze objects from the Lei Ku T'ai; arrowpoint probably not associated with interment. (Yü-ho Chên.)

FIG. 83.—The Lei Ku T'ai mound: Tomb I, ready for measuring.

FIG. 84.—Western end of Tomb I, Lei Ku T'ai.

FIG. 85.—Mr. Tung getting out pottery found in the tombs at the Lei Ku T'ai mound.

FIG. 86.—Tombs I and II, Lei Ku T'ai; beyond, barley harvest in progress.

Important as the archeological work of our Expedition has been, a summary of the year's activities in China should include a statement concerning the perhaps still more gratifying success we have had in accomplishing what was the fundamental object of our Expedition; namely, the establishment of a cooperative agreement between ourselves and the Chinese authorities with regard to archeological research. This agreement establishes for the first time, a mutually beneficial relationship between Chinese and Western archeologists, which will prove to be, let us hope, a dignified working basis for more enlightened scholarship and valuable scientific research in this increasingly important field. The cooperative agreement between ourselves and the Chinese authorities was confirmed by the unsolicited appointment of Mr. Bishop as Honorary Advisor in Archeology to the Historical Department of the Chinese government, and, later, by the permissions granted to our Expedition, not only by the Governor of Shensi and the Director of Education for Honan, to excavate within their respective provinces, but also by the Ministry of Education, to excavate anywhere in China.

ETHNOLOGICAL AND ARCHEOLOGICAL RECONNOISSANCE IN ARIZONA

During August and September, Dr. Walter Hough, head curator of anthropology, U. S. National Museum, carried on ethnological and archeological reconnoissance work in Arizona. Revisiting the White Mountain Apache after an absence of several years, effort was made to ascertain the present status of these Indians in comparison with their condition and attitude towards innovations some years ago. Measures adopted for the welfare of the Indians give imperceptible results for a period; then the innovation is gradually accepted and finally reaches the effective stage among the larger number of Indians. In this way schools, hospitals, etc., slowly enter the consciousness of the Indian. Attempts to hasten matters unadvisedly in the past have resulted in disastrous failure, blocking the orderly course of reforms. More basic and perhaps more important is the extension of commerce and the consequent realization by the Indian of the value of money. Last year two prominent Apaches occupied American type houses. This step appears to mark the abandonment of the miserable, unsanitary tipi of brush which has held back the Apache during all his generations.

Among the Hopi it is becoming apparent that changes are in progress that will profoundly affect the persistence of this Indian group.

The young men are qualifying as artisans and necessarily the work entails a permanent absence from the pueblos. Most of them are employed in the mechanical work of the Santa Fe railroad. They

Fig. 87.—A combination of old and new. Hopi Indian, Walpi, Arizona.

receive large wages and are much esteemed for their skill. The result of this on the integrity of pueblo life is on the eve of becoming disastrous, as the older people are left on their own resources without able help. This phase in the history of the Hopi was unexpected as a disintegrating element. No one suspected that the Hopi would be

caught in the industrial maelstrom, especially as the Rio Grande Pueblos never progressed in this direction.

The archeological results of the reconnoissance were the location of several hitherto unidentified ruins, notably a large ancient settlement of apparently pre-pueblo age about five miles from Whiteriver, Arizona. A careful examination was made of the numerous picture writings on the rocks in the vicinity of Holbrook. Most interesting of these depictions was a group of snake dancers clothed in archaic costume.

FIG. 88.—Apache house, Oak Creek, Arizona.

On the journey Dr. Hough made a careful inspection of museums at Santa Fe, Los Angeles, Pasadena, San Francisco, Salt Lake City, and Denver.

MARSH-DARIEN EXPEDITION

Mr. R. O. Marsh continued during a part of 1924 his work of exploration in hitherto almost unknown regions of the Isthmus of Darien. A considerable party of scientific men accompanied the expedition, among them Mr. John L. Baer, who was deputed to care for the anthropological work on the part of the Smithsonian. The Expedition experienced a great misfortune in the sudden illness of Mr. Baer while proceeding up the Chucunaque River. He was transported

6

Fig. 89.—Chocó Indian house with open sides.

Fig. 90.—Chocó Indian man and woman.

FIG. 91.—1, Tule (San Blas) Indians; 2, Tule girl in native costume; 3, Tule loom.

immediately to the Coast, but the illness terminated fatally on May 28, the Institution being advised by the Navy Department of Mr. Baer's death.

The route followed was from Balboa to San Miguel Bay, through Darien Harbor and up the Tuyra River to the village of Real. There a change was made to smaller boats and the Rio Chucunaque

FIG. 92.—Tule Indian women in native dress.

ascended to Yavisa, near which a permanent camp was established. A visit was made to the Chocó Indians, who occupy the middle river valleys above tidewater, and to the Cuna, who live in the higher river valleys and mountain districts. The Chocó have a local government, live in large, well built community houses, and subsist on rice, bananas, plantains, corn, and yucca. They are expert fishermen, diving into

deep pools and catching certain kinds of rock fish in their hands.
Their religion is a form of primitive belief in the influence of good
and bad spirits. Mr. Marsh observes that they are a happy, careless,
childlike people, friendly if well treated, very Polynesian-like, wearing
breech-cloths, but decorated with beads, silver earrings, and wrist
bands, and wreaths of gay flowers.

Fig. 93.—Tule Indian children.

The Cuna have a higher culture than the Chocó, are monogamous,
have hereditary chiefs, families have separate houses, and large houses
are used for tribal meetings and ceremonies. They raise long staple
tree cotton, dye and weave cotton into cloth and hammocks, grow
corn, plantains, bananas, yucca, coffee, chocolate and sugar cane.
They are adepts with the bow and arrow and blowgun.

Fig. 94.—Chepu, Marguerite, Olo: Tule (San Blas) Indians.

Fig. 95.—Along the Caribbean coast. Tule (San Blas) Indian village and canoes.

The party proceeded up the Chucunaque River with great difficulty owing to barriers of drift logs, at last reaching the Cunas Bravos, who were regarded as hostile. The Cunas Bravos are agriculturists and exhibit a lower degree of culture than the Cunas of the lower river. The chief of the Cunas Bravos spoke good English, having as a young man shipped at Colon on an English vessel and in 12 years had sailed over half the world. It was at this point that John L. Baer became sick.

Activities were next transferred to the San Blas Indians, who inhabit a long stretch of the north coast of Panama. These Indians, who number approximately 40,000, have always kept aloof from the white man, realizing that contact with other races would work their undoing. Amicable relations were established with them and many interesting specimens of their arts and industries were collected for the National Museum. The San Blas Indians have an advanced social organization, with a ruler who could perhaps be properly classed as a king. Through the San Blas, Mr. Marsh came in contact with hundreds of " white Indians " whose presence in Panama has been known for a long time, but who have not been examined by scientific observers. Individuals brought by Mr. Marsh to the United States have been carefully examined and tentatively stated, before field studies go more fully into the matter, to present a form of albinism. Mr. Marsh states that light brown Indians having one white parent reproduce white, light brown, and dark brown children. The San Blas segregate the white children at the age of puberty, and from such information as was furnished it is estimated that one thousand individuals exist in the San Blas region. Mr. Marsh states that the San Blas Indians are capable of assimilating the essentials of modern civilization, and believes that these Indians should be given the chance to develop without contact with alien blood.

ARCHEOLOGICAL INVESTIGATIONS AT PUEBLO BONITO, NEW MEXICO

Throughout the summer months of 1924, Mr. Neil M. Judd, curator of American archeology, U. S. National Museum, continued his investigation [1] of Pueblo Bonito, a prehistoric Indian village in northwestern New Mexico, under the auspices of the National Geographic Society. In these researches there were employed ten white men, six of whom were technical assistants to Mr. Judd, and thirty-seven

[1] Smithsonian Misc. Coll., Vol. 72, Nos. 6 and 15; Vol. 74, No. 5; Vol. 76, No. 10.

FIG. 96.—Upon conclusion of the 1924 excavations, Pueblo Bonito with its 350 ground-floor rooms, its 30 ceremonial chambers, its numerous alcoves, passageways and architectural vagaries presented a most fascinating panorama. Exposed for the first time since its abandonment 1,000 years or more ago, Pueblo Bonito seems almost alive at times, echoing the songs of its vanished builders. (Photograph by O. C. Havens. Courtesy of the National Geographic Society.)

Indian laborers. The explorations of 1924 mark the fourth season of the five-year Pueblo Bonito project, inaugurated in 1921 after a thorough reconnoissance of the entire Chaco Canyon region.

During the years 1921-1923 the Expedition completed the excavation of the eastern and northern portions of Pueblo Bonito. It is in the former section of the ruin that those dwellings last constructed are to be found; in the northern section are slightly earlier houses erected above the razed walls of part of that original settlement which preceded and formed a nucleus for the great communal structure now known as Pueblo Bonito. In 1924 the Expedition confined its principal activities to the western half of the ruin where rooms of both early and late construction exist. From these much new data were obtained.

As one result of the past season's explorations, it is now reasonably certain that no more than two major periods of occupancy are present in the ruins of Pueblo Bonito. These were contemporaneous throughout many successive generations and yet one was pioneer to the other. During the second period, three separate types of masonry were evolved. The culture of the original Bonitians appears to have been quite distinct; the masonry of their dwellings, the form and furniture of their ceremonial rooms and perhaps even their daily life differed from that of their later associates.

In that portion of the pueblo recently excavated are to be seen rectangular dwellings whose walls were constructed both with hard, laminate sandstone and dressed blocks of similar but more friable material. These rooms adjoin and even encompass earlier habitations in which broad, thin slabs of sandstone were utilized with abundant quantities of adobe mud as the characteristic building material. The earlier dwellings were built on a much lower level of occupancy; the later structures are especially noteworthy for the perfection and symmetry of their masonry, the trueness of their corners and the uniform regularity of their dimensions. Kivas associated with these latter dwellings are, for the most part, of smaller diameter than those observed elsewhere in the ancient village.

Among the older habitations excavated last season were four rooms which had been utilized as burial chambers. A majority of the 71 bodies interred here had been placed upon burial mats and were accompanied by mortuary offerings, including basketry and earthenware vessels. Such personal ornaments as were worn by the deceased at the moment of death were not removed. Whether the burials represent the first or second period of occupancy is a question still undetermined. But a curious fact in connection with these interments

FIG. 97.—Dwellings of the older portion of Pueblo Bonito were characterized by rude masonry, heavily plastered with mud, and by secondary supports for the ceilings of first story rooms. (Photograph by O. C. Havens. Courtesy of the National Geographic Society.)

FIG. 98.—Disturbed burials and mortuary offerings on one of the older rooms of Pueblo Bonito. Prehistoric vandals had ravaged each of the burial chambers. (Photograph by O. C. Havens. Courtesy of the National Geographic Society.)

is that most of them were disturbed during prehistoric times. It is quite apparent that enemy peoples had entered the rooms and ruthlessly disarranged the bodies, perhaps in search of turquoise and other treasures highly prized by primitive peoples of the Southwest. With the cultural objects recovered by the Expedition are many jewels of such exquisite beauty and artistic merit as to have proven entirely irresistible to those aborigines not related to the former inhabitants of Pueblo Bonito.

In the large number of earthenware vessels collected from these four burial chambers and elsewhere two outstanding types of ornamentation appear. Although these types were frequently found directly associated with each other, one is thought to belong essentially to the original Bonitians while the other is believed more characteristic of their neighbors of the later period. Chronologic studies made in the two principal refuse mounds and about the outer wall of the pueblo illustrate a gradual development of local pottery technique throughout the entire period during which Pueblo Bonito was inhabited. But a certain perplexity still obtains in the evidence relating to this ceramic material. This doubt is due mainly to the fact that the later arrivals were obviously the first to abandon the village and that all serviceable utensils they left behind were subsequently salvaged by those families which still clung to their ancestral home, the older or pioneer section of Pueblo Bonito.

Several of the baskets recovered from the four burial rooms are of types rarely, if ever before, recovered from prehistoric ruins other than cliff-dwellings. Shallow, elongated trays of unusually fine weave and deep, cylindrical baskets' of rather coarser fabric are included in the collection. In addition, there were obtained bifurcated baskets such as have been found heretofore only in cave villages of northeastern Arizona and southeastern Utah. Three of the earthenware vessels in the season's collection simulate the general form of these two-legged affairs of unknown import.

The Expedition of 1923 uncovered a puzzling network of foundation walls on the outer northeast side of the great ruin. This series was still further exposed during the past summer and it is expected that the remaining portion will be brought to light in 1925, the final year of the Pueblo Bonito project. The fact that these interlacing walls lie buried under many feet of blown sand makes their exposure a slow and arduous task. The studies already pursued in this area suggest that these foundations were prepared, but never utilized, for a contemplated and sizable addition to the village.

Fig. 99.—Pueblo Bonito kivas are always subterranean or surrounded by walls to simulate the subterranean position required by prehistoric religious conceptions. (Photograph by O. C. Havens. Courtesy of the National Geographic Society.)

Fig. 100.—Excavating one of the major kivas of Pueblo Bonito. The flat roof of the subterranean room, 44 feet in diameter, had been supported by four wooden pillars. (Photograph by O. C. Havens. Courtesy of the National Geographic Society.)

Fig. 101.—The ancient potters of Pueblo Bonito ornamented their food bowls with a wealth of geometric design. The vessel at the lower right is 6½ inches in diameter; others in the collection vary from 2 inches to 13 inches. (Photograph by Charles Martin. Courtesy of the National Geographic Society.)

Fig. 102.—Pitchers from prehistoric Pueblo Bonito. The duck-shaped vessel in the lower row is 5¼ inches high. (Photograph by Charles Martin. Courtesy of the National Geographic Society.)

FIG. 103.—Cylindrical vessels bearing the hachured ornamentation characteristic of the later period of occupancy at Pueblo Bonito. The vase at the right is $11\frac{1}{2}$ inches high. (Photograph by Charles Martin. Courtesy of the National Geographic Society.)

FIG. 104.—Water jars are among the rarest of Bonitan antiquities. These two vessels are probably related to the earlier period of occupancy for their ornamentation differs noticeably from that employed by potters of the later period. (Photograph by Charles Martin. Courtesy of the National Geographic Society.)

Among the many interesting discoveries made in 1924 is one which affords some conception of the community pride which prevailed during the heyday of Pueblo Bonito. The two principal refuse mounds, where floor sweepings and other trash was deposited, were each surrounded by stone walls. These were increased in height as the mounds grew in elevation. Their obvious purpose was to prevent scattering of ashes and light debris before the tireless canyon winds. Two flights of stone steps were later constructed over the northern wall of the east mound to facilitate access to its summit.

Other walls whose intended function remains unsolved were also exposed during the summer. One of these, at no point more than two feet high, extends in a northeasterly direction a distance of 500 feet from the outer southeast corner of the ruin.

Explorations in Pueblo Bonito were brought practically to completion by the 1924 Expedition. There remain for next year additional chronologic studies and minor excavations, the fundamental purpose of which will be to explain certain still doubtful matters of prime importance. It is already evident that Pueblo Bonito was occupied throughout a much longer period than was originally suspected. Amalgamation of the two distinct groups that comprised its later population resulted in a prehistoric village whose fame reached the remotest corner of the Southwest. During the period of its greatest affluence, Pueblo Bonito was undoubtedly a center at which representatives of many unrelated tribes met for barter and trade. Evidence has been obtained that the Bonitians engaged in commerce with primitive peoples of the Pacific Coast and even so far distant as the valley of Mexico; indeed, there seems to be no cultural area in the Southwest of comparable antiquity whose members were not attracted to Pueblo Bonito. The current explorations of the National Geographic Society, therefore, have a direct bearing upon the distribution of ancient Pueblo peoples. With a considerable portion of its unwritten history recorded; with the years of its construction determined with reasonable accuracy—a former hope that seems more and more within the realm of possibility—Pueblo Bonito is destined to become a yardstick, so to speak, by which the culture of other prehistoric southwestern ruins may be gauged. As Pueblo Bonito was the most influential village yet discovered in the Pueblo area of pre-Columbian times so is it today the most important ruin in that area—a ruin which holds the key to many secrets that have long puzzled American archeologists.

PREHISTORIC ABORIGINAL CULTURE OF THE GULF STATES

Of the aboriginal culture areas within the boundaries of what is now the United States, there are two which, although related, are widely diverse. One of these lies in the four States, Colorado, Utah, New Mexico, and Arizona, the other formerly extended over portions of the Gulf States, Florida, Georgia, Alabama, Mississippi, Louisiana, or practically the Lower Mississippi Valley, Georgia, and Florida. In both these areas there was an aboriginal culture prehistoric and thoroughly Indian, which was on the decline when the region was first visited by white men. Each area was inhabited by Indians speaking different languages or dialects, but who had cranial similarities, like means of obtaining a food supply, related social customs, rites, and mythology. Ethnologists may have different opinions as to which culture reached the higher development, but they generally agree that we need more accurate knowledge of both to form a final judgment of their character.

The amount of scientific research that has been devoted to these two culture areas is quite unequal. The pueblo field has attracted so many investigators that they far outnumber those studying all other culture areas in the United States. Notwithstanding the fact that the archeology of the Gulf States is as attractive as that of the Pueblos, it has few votaries, possibly because the Pueblo culture has survived less changed into modern times. The prehistoric culture of the Gulf States may be termed Muskhogean, from the dominant tribe of the Creek confederacy, though it is not limited to people speaking any one language.

The southwest area has long been a favorite subject of study for members of the Bureau of American Ethnology. The Smithsonian was not only a pioneer worker in this area, but also for many years the sole investigator. Of late, however, this field has attracted many field workers and is now in good hands, producing annually many discoveries.

The southeastern area, although not wholly neglected since the epoch making work of Clarence B. Moore, is now making strong appeals for archeological investigation which have attracted members of the Bureau of American Ethnology. The Chief has inaugurated a new plan of work in this area, the first step being a determination of the aboriginal culture of Florida and an adequate diagnosis of its character and horizon. On the south and east, boundaries of the Muskhogean culture are limited by the Gulf of Mexico and the Atlantic Ocean; its extension northward and westward is more difficult to discover.

WORK IN FLORIDA

Archeological work in Florida was begun at St. Petersburg, Tampa
Bay, in the winter of 1923-1924. It was discovered that the prehistoric

Fig. 105.—View of a road on Weeden Island, St. Petersburg, Florida, showing
semi-tropical vegetat on. (Photograph by Beck.)

inhabitants of the Everglade region and the Florida Keys showed
scant evidences of a relationship to the Muskhogean culture, but
from Tampa Bay north into the other Gulf States, archeological data
supported linguistic evidences of Muskhogean influences.

7

Following the above-mentioned plan, Weeden Mound, near St. Petersburg, was excavated by the Chief, assisted by Mr. M. W. Stirling, through the kindness of Mr. E. M. Elliott and the Boulevard and Bay Land and Development Company. These investigations, preliminary results of which were published last fall,[1] reveal that the culture of northern Florida was in prehistoric times different from that of southern Florida.

The character of the objects obtained from Weeden Mound, as shown in the above-mentioned pamphlet, indicates that the former inhabitants of this site were allied to the so-called Lower Creeks who once lived on the Chattahoochee and Flint rivers in Georgia. These were of the same race as the Upper Creeks, denizens of the Tallapoosa and Coosa valleys in Alabama, and as the Creeks were the most numerous representatives of Muskhogean culture they may be regarded as typical of it. The archeological relation is mainly determined by the designs on the pottery, which in the case of the ceramic objects from the Lower Creeks collected on the Chattahoochee and Flint, figured and described by Mr. Clarence B. Moore, and those from Weeden Mound are practically identical. In both localities pottery designs are outlined by pitted or perforated lines, which designs and technique occur also on pottery found at Tarpon Springs, Crystal Springs, and at various other localities northward on the west and northwest coast of Florida.

There is a similarity in mortuary practices throughout the greater part of the Muskhogean culture area which occurs also in the Weeden Mound. The actual method of burying the dead among the Upper Creeks, as shown by the Graves collection at Montgomery where the skeletons were placed in urns (figs. 112, 113), is unlike that at Weeden Island, where they were free or placed in baskets. Urn burial has not been recorded among the Lower Creeks but a secondary interment or burial of skeletons in urns after the flesh had been removed has been found in the islands on the Georgian coast. Bunched burials occur throughout the whole Muskhogean area. So far as we at present know, urn burial (fig. 114) is a localized development found in different localities in the Gulf States but the bunched secondary burial of skeletons is a general feature in this culture.

The cluster of mounds on Weeden Island near St. Petersburg is easily distinguished and its site has been lately designated Narvaez Park from the Spanish leader of the expedition in the sixteenth century that ended so disastrously. On the largest mounds of this

[1] Smithsonian Misc., Coll., Vol. 76, No. 13, 1924.

cluster formerly stood Mr. Weeden's house, but earlier the Indians
used it as an eating place to which they brought their canoeloads of
shellfish, cooked the mollusks and ate the soft parts, throwing away
the shells. Mr. Weeden's old home has now been torn down and a
pavilion erected on its site. Previously a trench was run into this
mound but it revealed little besides shells alternating with layers
of black sand, discolored by decomposed vegetable soil. A few frag-
ments of pottery rewarded excavation in this mound but it was singu-
larly poor in artifacts of any kind.

FIG. 106.—Flexed burial, lower layer, Weeden Island, Florida.
(Photograph by Beck.)

The conclusions arrived at by studies of this large mound were that,
while its top may have served as an observatory or even the site of a
building like a chief's house, it was essentially a kitchen midden
composed of rejected shells or whatever human artifacts may have
been lost in it by the aborigines. Almost every village site in the
Gulf States culture area has a mound larger than the rest and dom-
inating it, which was used as the foundation of the houses of the
chief or of the temple in which, in some cases, the fire was kept con-
tinually burning. Such mounds were Cahokia in East St. Louis, Mo.,

and Etowah, near Cartersville, Georgia. This dominating mound is here designated the Acropolis.

Dr. Fewkes made trial pits in various other mounds of the Weeden cluster and among other elevations found a low mound of sand in which grew a few trees and scanty plants but showed no considerable number of shells. It gave promise of a much greater reward and to it the main work was devoted through the winter and early spring of 1923-24. It was found to be a burial mound concealing numerous human skulls, much pottery, and other objects of various kinds. The most striking specimens were secondary burials of human bones, of which 440 bunches were found.

These remains followed the almost universal aboriginal burial customs among people of the Gulf States. After death the bodies were allowed to decay and the flesh removed from the skeleton by " bone pickers " after which the large bones and crania, done up in bundles, were in due time placed in heaps and covered with earth, forming a mound over a dune of coral sand.

According to contemporary writers, one custom of the ancients in preparing the " bundles " for burial after flesh had been removed was to paint the skulls with vermilion. Dr. Fewkes verified this custom at Weeden Mound, for he found the paint, now in some instances dry dust, and readily removed from the bones with a brush. The skeletal material was in a very fragile condition and fell to pieces almost at the least touch.

It was noticed that a cross section of the mound exposed by a trench through it, revealed a stratification composed of two marked layers of finest sand through which are darker narrow seams of black or dark brown color. The difference between these layers is mainly indicated not by the color but by the contained pottery. The upper layer is capped by a thin superficial covering of sand which represents the modern deposit. Below it is the thick upper stratum in which were found specimens of decorated pottery, either in fragments or whole pieces, the latter in one or two instances cached. Two views of a fine bowl are shown in figure 108, *a* and *b*. The whole pieces are invariably artificially pierced by an irregular opening in the bottom by which the bowl or jar was " killed," evidently to allow the escape of the breath body or life of the bowl. In a lower layer, the pottery is coarse, undecorated, and scattered. It contained also a few implements and utensils made of shell. It would appear that the lower layer was used as the burial place of the archaic Floridian

Fig. 107.—Circular stone disk with eccentric perforation, popularly called an anchor, presented by Mr. and Mrs. Griner, Caxambas, Florida.

Fig. 108.—Two views of bowl with incised and relief decoration, from Weeden Island, St. Petersburg, Florida. Restored from fragments.

(a) Shows conventionalized figure of a bird.
(b) Figure on side at right angles to a.

people and from its general facies Dr. Fewkes allies it with the lower
layer that has been recorded in Cuban and other West Indian Islands.

Only in rare instances is the pottery of the upper stratum painted,
but almost every fragment is decorated with designs whose outlines
consist mostly of rows of pits, in rare instances accompanied with
relief decorations (fig. 108). Little resemblance appears in the designs
on the decorated pottery from Weeden Island to those on the pottery
of the Tainan inhabitants of the West Indies, but the likeness of
utensils from the lower layers on these islands and on the peninsula
of Florida is striking.

Dr. Fewkes found no specimens of European provenience in the
Florida mound half excavated by him at St. Petersburg, which indi-
cates that the village sites were pre-Columbian. A food bowl of
coarse, undecorated black ware was found on top of the lower layer
and probably is a survival of the archaic population.

From the designs depicted on the pottery in the upper layer at
Weeden Mound and comparison with that described from mounds
on the Chattahoochee and Flint rivers of Georgia and other Gulf
States, Dr. Fewkes regards this pottery as not only characteristic but
as belonging to the highest type of ceramics in the Muskhogean
culture area.

WORK IN ALABAMA AND TENNESSEE

When the Wilson dam over Tennessee River at Muscle Shoals,
northern Alabama, is finished, the back water of the river will
flood a considerable section of its banks, covering several prehistoric
mounds and permanently concealing them. In order to rescue a
typical collection from these mounds before their submergence, the
Bureau allotted to Mr. Gerard Fowke a small sum of money for the
excavation of a kitchen midden and sand mound at the mouth of
Town Creek, a few miles from Courtland. In the sand mound Mr.
Fowke found human burials and accompanying mortuary objects.
The most important discovery at this mound consisted of three rare
copper reel gorgets, only a few of which have thus far been found.

On his trip to Muscle Shoals to inspect the work, Dr. Fewkes
found several typical mounds higher up on the river banks which
would well repay excavation. The largest of these (fig. 110), which
is here called the Acropolis, was the foundation of a sun-fire temple.
It lies in full sight of the Florence-Sheffield road and has long been
a landmark, as it is probably one of the highest mounds in the Valley
of the Tennessee. The present owner of this mound is thoroughly

alive to its value as an asset to the two cities, Florence and Sheffield, and has opposed efforts to cart it away for roads. Its value as a
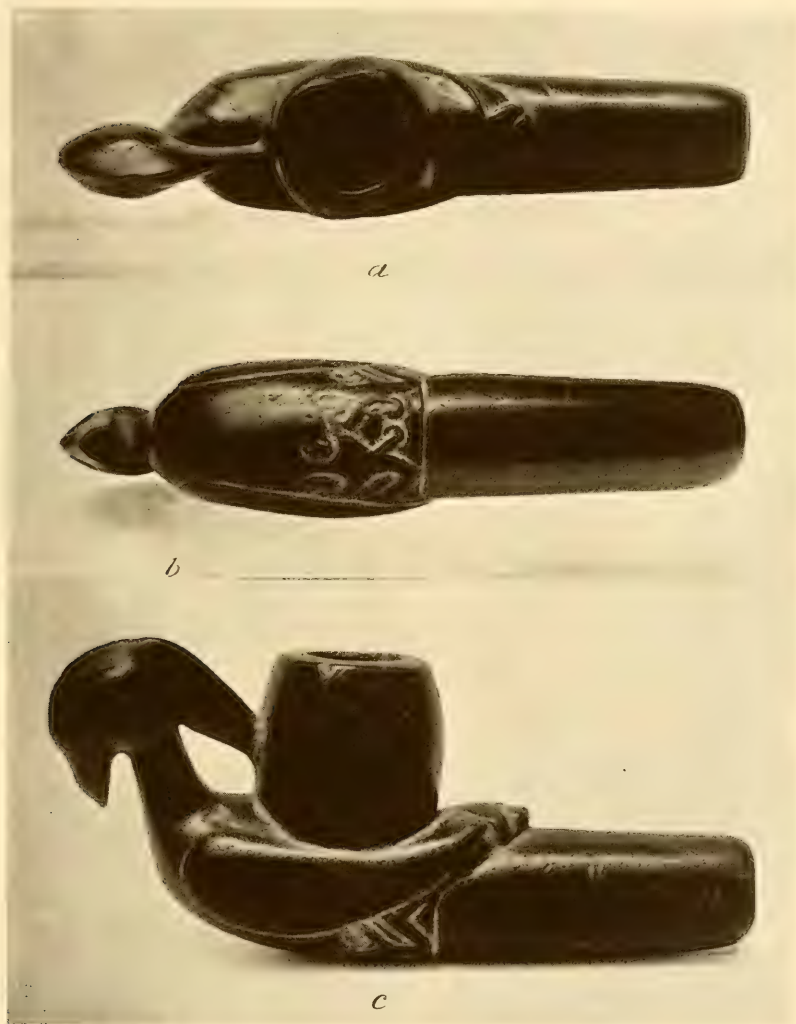
FIG. 109.—Steatite pipe, found by Weil Harris near Hyde's Ferry, on Cumberland River, about seven miles below Nashville.

(a) From above. Length 10".
(b) From below. Width 2¼".
(c) Side view. Height 2¼".

landmark is much greater than the value of the contents for building causeways or roads.

Fig. 110.—Large mound on side of road between Sheffield and Florence,
Alabama.

Mullett

Fig. 111.—(*b*) From photograph of a Catawba bowl in collection of Wm. T.
Thackston, Greenville, S. C. Published by permission of owner. (*c*) Raised
figure on pottery fragment from Weeden Island, Florida.

Dr. Fewkes visited the battlefield at Shiloh and inspected the remains of an aboriginal village now indicated by mounds. The beautiful pipe excavated years ago from one of these elevations he regards as the finest art product of the old Muskhogean culture. Four life size illustrations of this pipe, from *Records of the Past,* July, 1902, represent a kneeling human figure, black in color, whereas the original color is brown.

The shell mound at Town Creek yielded many specimens but they indicate a lower cultural condition than the village cluster on the Shiloh battlefield, as might be inferred from the character of the food supply.

In November Dr. Fewkes made a trip to Montgomery, Alabama, in order to locate prehistoric mounds and study the collections made near that city. He also desired to familiarize himself with the energetic work of the Alabama Anthropological Society. The visit was brief but he enjoyed the privilege of inspecting several collections of antiquities and was guided to several mounds by Mr. Peter A. Brannon, President of the Society, and other members, to whom he owes many thanks.

Montgomery is situated near the heart of the Upper Creek country and the collections of aboriginal objects made in the neighborhood of that city contain several unique Indian objects not yet described. Among these may be mentioned the burial urns of the Graves collection. Figures 112-114, published by permission of Mr. Graves, show a number of these bowls, vases, and jars used in urn burial. After death the flesh was allowed to decay and, having been removed, the bones were put in a deep vase and covered with a flat food bowl that was ultimately inhumated. The cemetery where these urns occur was situated in a corn field in which was a circular saucer like depression called by the negroes an " Indian talk house," evidently an ancient council house. An excavation of this subterranean room would probably yield what is much needed, a knowledge of architectural details as well as archeological treasures. While several of these urn burial vessels are rude undecorated pottery, there are others whose surface was incised with ornamental designs of a geometrical form. As a rule this pottery is inferior to that found at Weeden Island or on the Black Warrior River. Mr. Graves' collection also contains several unpublished shell disks decorated with finely incised naturalistic designs which are characteristic of early Creek symbolism.

On his visit in Montgomery, Dr. Fewkes was enabled to make several excursions to numerous prehistoric village sites. Among the

FIG. 112.—Burial urns from Pintlala Cemetery, Lowndes County, Alabama.

(a) From Cemetery, Cowles Lake, Elmore Co., Ala. Tuckbathie Bend, Tallapoosa
    River. Diam. 12″ x 8″. Inverted over chest of human skeleton. Graves collection.
(b) Collected by E. M. Graves and Dr. R. P. Burke. Diam. 12″ x 7″. Found 30″ below
    surface, inverted over knees of human skeleton.
(c) Collected by E. M. Graves and Dr. R. P. Burke. Urn 18¾″ x 13″. Inverted
    when found; full of ashes and bones showing influence of fire. Side of jawbone
    of carnivorous animal. Possibly cremation. Buried 36″ under surface. Graves
    Collection.
(d) Urn from Graves Collection.
(e) Design on cover rim.

Fig. 113.—Burial urns from Pintlala Cemetery, Lowndes County, Alabama.

(a) Diameter 20″ x 14″. Contents, two adults and one adolescent. Buried 36″ to 40″ deep. Double cover. Eagerton Collection.
(b) Same as (a).
(c) Collected by E. M. Graves and Dr. R. P. Burke. Diameter of urn 24″ x 14″; covered by broken fragments of pottery. Contents, traces of child's skeleton, charcoal and ashes. Brannon Collection.
(d) Collected by E. M. Graves and Dr. R. P. Burke. Diameter of urn 18″ x 6″; diameter of cover 15″. Contains fragments of child's skeleton and 12 beads. Burke Collection.
(e) Burial urn with bones.
(f) Cover of urn (fig. d) with incised decoration on rim.

Fig. 114.—Burial urns from Pintlala Cemetery, Lowndes County, Alabama. (a) and (c) collected by E. M. Graves and R. P. Eagerton, Graves' collection; (b) and (d) collected by E. M. Graves and Dr. R. P. Burke, Burke collection.

(a) Diameter 14" x 10"; cover 14¼" x 6". Contents, fragments of child's skeleton.
(b) Diameter 12" x 7"; cover 14¼" x 6". Contents, remains of small infant. Buried two feet deep.
(c) Diameter of urn 15" x 10"; cover 14" x 6". Contents, child's skeleton; associated with it, shell gorget and clay image of a woman 5½" high.
(d) Diameter 14" x 10"; cover 14" x 6". Contents, part of skeleton of adult. Lower vessel has columnar ridges on neck.
(e) Plowed up by Dock Groves, who gave it to Chas. and Ed. Hinderer, who later presented it to E. M. Graves. Contents, remains of two adults, one child.
(f) Urn with four handles.

most interesting was to the site of old Tuskegee and Fort Toulouse where William Weatherford surrendered to General Jackson at the close of the Creek war. The Indian settlement, Tuskegee, was most picturesquely situated at the junction of the Coosa and Tallapoosa rivers, together forming the Alabama River. Several other mounds situated near Montgomery were visited, including one at the ford where it is claimed De Soto crossed the Tallapoosa.

Dr. Fewkes examined several Indian sites and mounds of size near Nashville and Lebanon under guidance of Mr. P. E. Cox, State Archeologist of Tennessee. The most instructive were large mounds near which are stone walled graves that had never been opened. The excavation of one of these is now being made by the Bureau under supervision of the Chief. At Lebanon a rare form of bird-pipe made of steatite shown in the accompanying figure (fig. 109) was purchased for the Museum. The large mound at Lebanon is situated in a corn field and surrounded by a low embankment of earth and accompanying moat, indicating a fortification. The most remarkable object seen on the visit to this mound is the stone idol shown in figure 116. This idol was ploughed up a short distance from the base of the mound, suggesting that the elevation was formerly a temple or house of a chief, upon which it once stood.

In a determination of the Muskhogean culture area as fixed by the archeologist, we find traces of it in South Carolina, somewhat modified on account of the peripheral situation. Although little is known of the prehistoric pottery of South Carolina, Dr. Fewkes has obtained a photograph of a bowl (fig. 111) owned by Mr. Wm. J. Thackston, Jr., which is supposed to be ancient Catawba ware and shows Muskhogean influence. Dr. Fewkes examined several fine bowls of this ware decorated with figures of the sun and winged or plumed serpent, often conventionalized into incised geometric designs. These clearly indicate sun worship, a pronounced feature of the Muskhogean culture. The design on this Catawba bowl suggests parts of a highly conventionalized serpent.

A most instructive excursion near Montgomery was a visit to the Pintlala Creek cemetery in Lowndes County, Alabama, where the burial urns collection was found. These urns have been figured and described by Mr. Graves in *Arrow Points,* Vol. 6, No. 8. Additional figures of burial urns from islands off the Georgia coast and elsewhere have been given by Mr. C. B. Moore who has treated the subject of urn burials in a special article.

FIG. 115.—Pottery idol found with urn (c), fig. 114. Collection E. M. Graves, Montgomery, Alabama. Height, 5½ inches.

FIG. 116.—Stone idol found at the base of a large mound near Lebanon, Tennessee, by Mr. Ray Sellars. A photograph of the specimen published by permission of owner.

FIG. 117.—Excavators at work on shell mound at mouth of Town Creek, near Muscle Shoals, Colbert County, Alabama.

Although the visits of Dr. Fewkes to Tennessee and Alabama were much limited in time they have called attention to one or two instructive problems which await new observations for solution. Urn burial appears not to have been mentioned in the extended accounts of mortuary customs found in early documentary and historical descrip-

Fig. 118.—Prehistoric objects from Kittitas County, Washington.

(a) Pipe. Length 1⅞"; diameter ¾".
(b) Enlarged incised decoration of pipe (a).
(c) Stone pipe. Length 4½"; diam. ¾". Diam. of ferrule at one end 1⅛".
(d) Carved bone ornament or implement. Length 6½". Diam. at wide end 1".

tion of the Creeks. We know the bunched skeletons were placed in baskets for the bone house and later removed and buried in mounds, and may readily suppose the urn took the place of the basket, but are we justified in this supposition? Furthermore, as urn burial is not the common method of disposal of the dead, this exceptional custom

may have been used only for chiefs or priests. If so we have an explanation of its occurrence around the council houses. A large number of infants were buried in urns.

It seems evident that there were local differences in artifacts, especially ceramic symbols, in different localities or areas dominated by the Muskhogean culture which may be a parallelism with what occurs in the pueblo region, but this means renewed field-work to discover the ceramic facies of each area of population in the Gulf States.

The relation of the Muskhogean and Pueblo areas calls for archeological work west of the Mississippi along the Red River where many mounds have been reported. Until knowledge of the archeology of this area is more exact, theories of the relationship of these two culture areas to each other and of both to Old Mexico are futile.

During the past year Dr. Fewkes has received from the State of Washington two characteristic straight tube pipes of a variety which is interesting in a comparative way in studying the large steatite pipe collected by him at Lebanon, Tennessee. With the same collection came also an engraved bone object of unknown use. These objects are shown in figure 118.

REPAIR OF MUMMY CAVE TOWER IN THE CANYON DEL MUERTO, ARIZONA

During the past year, Mr. Earl H. Morris, at the request of the Chief of the Bureau, did some necessary repair work on the famous Tower of the Mummy Cave House in the Canyon del Muerto. This tower is approximately 30 feet high, and 11 feet 3 inches wide, and once contained three rooms. All woodwork on the first ceiling has been torn out, only the haggled ends of a few of the supports remaining embedded in the walls.

The cleanly peeled poles which supported the second ceiling are in place, and the third ceiling—or roof—is intact, presumably because of the difficulty which would have attended its removal.

Covering the supporting poles, there is a closely-laid layer of peeled willows. Probably it is one of the most handsome ceilings remaining in any ruin in the Southwest, its only rivals being the coverings of one or two rooms in the north side of Pueblo Bonito.

For an unknown length of time the Tower has been in a dangerous condition, due principally to its undermining by the elements. Originally there was a retaining wall rising from the very brink of the

ledge in front which held in place the fill of loose rock and refuse upon which the House of the Tower stands. Eventually all but the eastern end of this wall collapsed—probably because of the insecure foundation afforded by the abruptly sloping rock, and much of the material behind it poured down over the cliff. As time went on, the not infrequent winds which sweep past the cave with unbelievable

Fig. 119.—Tower from the west. New retaining wall at lower right-hand.

force whipped out the dust and smaller particles of rock until the southwest corner of the Tower was undermined more than three feet and the wall thence eastward almost to the opposite corner to a lesser degree.

As the Tower stood in the fall of 1924, the east wall was firm and secure, being bedded on the ledge to within $1\frac{1}{2}$ feet of its outer end.

8

The west wall had settled considerably, more toward the outer end than near the cliff, and at the top the wall had leaned away from the latter fully eight inches. The front wall had split away from the west wall, and the entire southeast corner had fallen except for a short distance at the very top. Evidently the upper half of this corner had come down since Mindeleff made his report of the site (16th Annual Report, Bur. Am. Ethn., p. 114).

As for the cracks in the west wall, they were noticeably wider in November, 1924, than they were a year previous. The condition of the unconsolidated mass beneath the front wall was such that the removal of half a dozen shovelfuls of earth would have loosened the large block just beyond its western end, the temporary wedging of which, alone, had prevented the entire collapse of the masonry. In addition to the periodic action of the wind, each visitor who passed from the eastern to the western part of the cave detached a portion of the loose mass below the wall farther down the slope, and sent clods and pebbles rattling over the cliff. Thus before many years it was inevitable that the block would have been loosened, and the Tower would have gone down to its destruction. Hence it was considered that the first remedial effort should be centered upon providing a secure foundation for the ancient masonry.

To this end Mr. Morris and his party devoted November 11 to 14, inclusive. The force consisted of three white men and six Indians, with a seventh on the last day. There was no difficulty in obtaining stone, as plenty of it from fallen walls was strewn down the slope at the west end of the eastern section of the cave. Satisfactory adobe was found only in the stream bed several hundred yards away. Owing to the arduous climb, the Indians were scarcely able to provide enough material to keep the masons busy. During the five days, buttresses were built beneath and enclosing the large blocks under the west end of the Tower, and under the undermined portion of the latter, continuing back to the limit of undermining, and extending well forward of the masonry. At the junction of the two, wedges were driven to knit the new work firmly to the old. From the east end of the buttress a retaining wall was built to connect with the remnant of the old one on the brink of the ledge, and the space behind it was filled, thus providing a platform instead of the former steep slope at the southeast corner of the Tower.

The total length of walls built was 26½ feet, and their average height was 4½ feet. The thickness of the buttresses varied with the space they were to occupy. From a minimum of 1½ feet, they ranged to a

Fig. 120.—Looking west along the Tower at the beginning of repair.

Fig. 121.—New foundation of Tower from in front. All masonry below dark lines is portion of repair work.

maximum thickness of 5 feet at the point where the wall was most deeply undermined. In bedding the masonry, the ledge was swept free from dust, and where it sloped abruptly it was chipped away to provide a secure attachment of wall to cliff.

It was Mr. Morris' original idea to use cement instead of adobe for mortar. However, it was found possible to obtain the same quality of clay used by the original builders, which is as hard as brick when dry, and it was decided to use this material, thus avoiding the expense of freighting cement from Gallup, New Mexico, 100 miles distant.

Although the foundation placed beneath the Tower should remove all danger from settling, other protective measures would be highly desirable. The front wall was not perpendicular when constructed. Up to the level of the second ceiling it sloped slightly outward, and thence upward leaned toward the cliff. Since it has parted from both side walls, the maximum strain falls at the point of greatest protuberance. Gravity, augmented by the tendency of high winds to produce a swaying motion, might cause the wall to buckle at the point of greatest stress and to topple outward. Rods with turnbuckles, anchored in the cliff with expansion belts and passing through plates on the outer side of the masonry, would prevent failure of this nature. It was hoped that these could be installed within the limits of the amount expended for protection in 1924, but this was not possible. In addition to the placing of the rods, the Tower should be further strengthened by the rebuilding of the southeast corner and its careful bonding to both the front and east walls. It is to be hoped that provision for this work can be made in the near future; for the Tower, which is one of the finest gems of aboriginal architecture in the entire Southwest, thus treated, would be preserved beyond doubt or question for centuries to come.

Besides the partial repair of the Tower, a breach was filled farther along the wall which continues westward therefrom, and a foundation was built beneath the high front wall of a room near the western end of the east cave.

STUDIES ON THE TULE INDIANS OF PANAMA

ETHNOLOGICAL AND LINGUISTIC STUDIES

The bringing of a party of eight Tule Indians from Panama to Washington in the middle of October by R. O. Marsh, mining engineer and explorer, has afforded J. P. Harrington, ethnologist of the Bureau of American Ethnology, the opportunity to make an
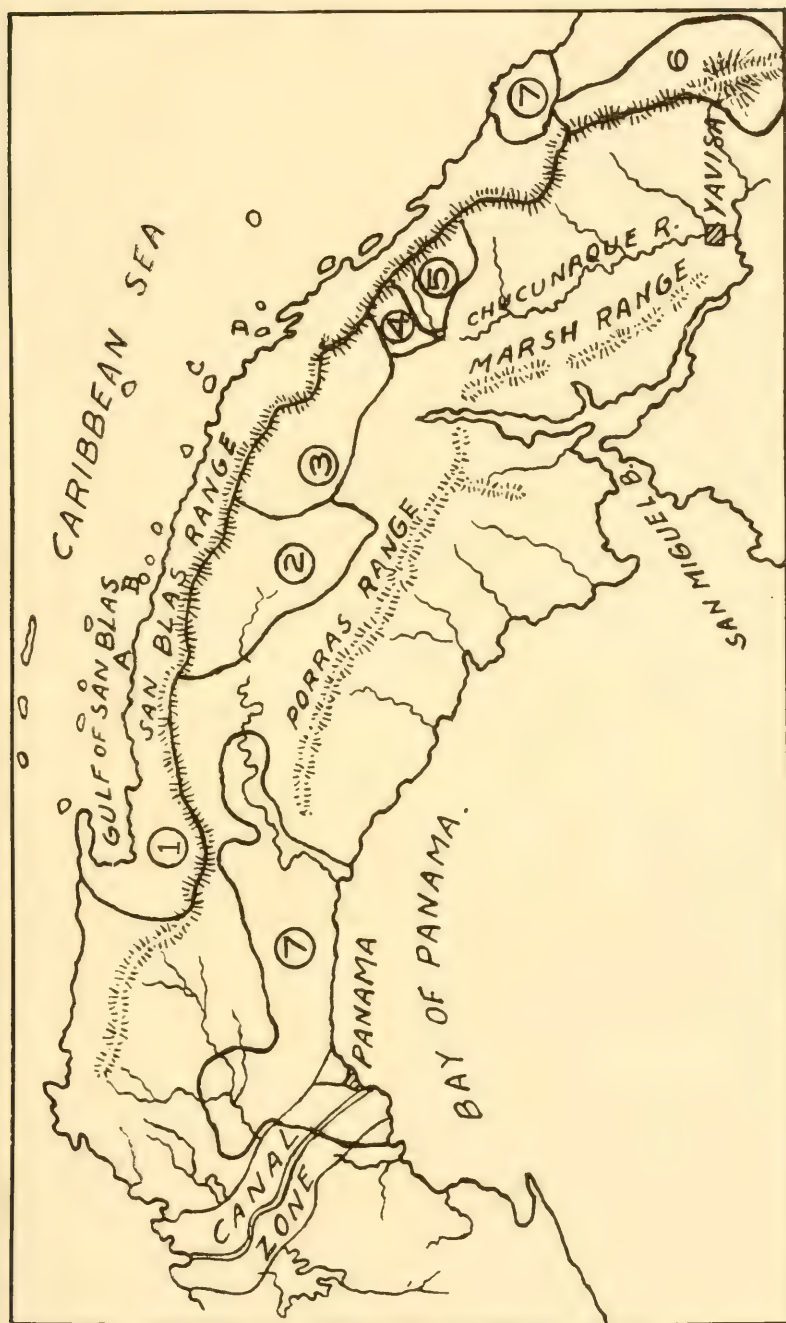
Fig. 122.—Map showing the tribal divisions of the Tule Indians of Panama. (1) Costeño, or Coast Tule. (2) Madung-andidola, headwaters of Rio Bayano. (3) Wala. (4) Mardidola, headwaters of Rio Chucunaque. (5) Inakunalilele, or Mountain Cuna. (6) Argidola, about Tacarcuna Mountain and at headwaters of Rio Tanela and Rio Arquía. (7) Negroid population. A. Yantuppu island. B. Tigandikki island. C. Agligandi island. D. Ustuppu Island.

extensive study of the ethnology and language of this little known tribe, said to number some 50,000 souls.

The Tule Indians, also known as Cunas, Comogres, and San Blaseños, live along the Caribbean coast of Panama from Murru (San Blas Point) to Armila (Port Obaldía), a distance of 120 miles. They still have their own tribal government from Kwibgandi to Cacardía, a strip of coast 30 miles in length. They formerly held the coast from the region of Eskarban (Port Escribanos), 15 miles west of San Blas Point, to include the delta region of the Rio Atrato, a strip of coast 220 miles long. The tribe also holds the San Blas range, which parallels the coast at a distance varying from 5 to 20 miles, from San Blas Point to the region about Tacarcuna Mountain, including portions of the Pacific slope of the range. The linguistically related Coiba held the isthmus to the west, including Colon and Panama. The linguistic stock to the south was the Chocó Indians, who now inhabit much of the Savana, Chucunaque and Tuira river drainages.

The tribe, according to the informants, is divided into six sections as shown on the accompanying map (fig. 122.) The Negroid population is closing in on the Indians and will soon work their extinction.

The Tule language has, with the Chocó, the distinction of being the most southerly Indian language of North America, and with the Huaimi of Panama that of extending from the Atlantic to the Pacific coast.

The informants are: (1) James Perry, Alice Perry and Margarita Campos from Yantuppu (A of map), a small island in front of Nargana, 22 miles east of San Blas Point; (2) Niga (Felipe) from Tigandikki island (B of map), 31 miles east of San Blas Point; (3) Igwa Nigdibippi, who is chief over 20 islands, and Olo Piniginya from Agligandi island (C of map), 64 miles east of San Blas Point; (4) Alfred Robinson and Tcippu from Ustuppu island (D of map), 71 miles east of San Blas Point. Alfred's father is Nele, chief of the island.

Three of the party, Margarita, Olo and Tcippu, are examples of Ibegwa or White Indians, of whom Wafer writes in 1699: " There is one complexion so singular among a sort of people of this country, that I never saw or heard of any like them in any part of the world. They are white and there are of them of both sexes. Their skins are not of such a white as those of fair people among Europeans, but 'tis of a milk white, lighter than the color of any Europeans, and much like that of a white horse. For there is this further remarkable

in them, that their bodies are beset all over with a fine short milkwhite down, which adds to the whiteness of their skins. They are not a distinct race by themselves but now and then one is bred of the coppercolored father and mother." The little island of Ustuppu has ten of these White Indians on it.

The Tule say that their ancestors used to live around the base of Tacarcuna Mountain, west of the mouth of the Rio Atrato, the highest peak in their territory, and that they spread from there up the San Blas range and coast. It was at that mountain that God, Olokkuppilele, created the Indians.

The language exceeds in softness and beauty the melodious Castilian. It has no sounds that do not ocur in English. Its sounds are only 17 in number, a e i o u g η d c s l r n b m w y. These occur single or double, as in Finnish, thus securing the required number of syllables for the formation of words; e. g., kwālu, potato, but kwallu, grease.

The Indians know hundreds of place-names of the coast and mountains. Chief Igwa has prepared a large map showing these places.

The large collection presented by Mr. Marsh to the National Museum has afforded unusual opportunity for investigation of material culture. The sociology and religion of the Indians have formed fruitful fields of study. To assist the work the Dictaphone Corporation has installed machines for recording texts and songs.

The vocabulary comprises names of places, persons, parts of the body, sociological terms and other data. Dictaphone records of extended discourse have been made which will serve as the basis for further study of the language.

In 1914 Mr. Harrington made a six weeks study of this language at the Southwest Museum in Los Angeles, California, the informant being a Tule boy who was brought from Panama Harbor to San Pedro on a private yacht. This work was conducted through the kind interest of Dr. Hector Alliot, then director of the museum.

STUDY OF THE TULE INDIAN MUSIC

A remarkable opportunity for the study of primitive music was afforded by the presence in Washington of a group of Tule Indians from the Province of Colon, in Panama. This study was made by Miss Frances Densmore. The Indians were brought to the United States by Mr. R. O. Marsh and became known as " white Indians " because of the fair skin of certain individuals. A frequent occurrence

of fair-skinned individuals in this tribe was noted by Wafer, who wrote concerning them in 1699. It is not unusual for parents of normal Indian coloring to have children with skin of a peculiar milky whiteness, blue eyes and pale yellow hair, the skin, in many instances, showing irregular blotches of light brown. A family may contain both dark and fair children. The group brought by Mr. Marsh comprised five adults, all of whom were dark in color, and three children who were fair. The study of their music was carried on entirely with the adult members of the group during November and December, 1924, and was made possible by the courtesy of Mr. Marsh.

VOCAL MUSIC

Among the Tule Indians brought to the United States was a chief named Igwa Nigdibippi who had made a special study of the tribal songs. If he were a member of our own race he would be termed a man of practical intelligence and artistic culture. The head chief of the Tule is an old man, and on his death Igwa may be elected as his successor. In view of this possibility Igwa is cultivating his knowledge of the geography of the region with its irregular coast line and hundreds of islands and " keys." He draws maps which show the location of the villages, indicating the approximate number of inhabitants in each. His care and ability in this work added weight to his statements concerning the music of his people, who do not adopt any songs from neighboring tribes but maintain their own musical customs. Associated with him in giving information were James Perry and his wife, Alice Perry, and Alfred Robinson who acted as interpreter. These three did not give the Indian names by which they are known at home, and the names here presented have been recently acquired. The recording of the songs was done entirely by the chief, a dictaphone being used for that purpose.

The singing tone used by the Tule chief was somewhat different from that used by the Indians of North America. It was even more artificial, with a " pinched," forced quality not particularly pleasing to the ear and impossible to describe in an accurate manner. The Tule songs are without instrumental accompaniment in our use of that term. The flute and rattle are sometimes played while the people sing and dance, and the singers sometimes clap their hands, but the flute and rattle do not seem to have either a melodic or a rhythmic relation to the song. No form of accompaniment was desired when the songs were being recorded and it was said that the voice was entirely alone in the " songs with stories." The flute was played dur-

ing the prolonged tones of the wedding music which occurred at regular intervals.

In this, as in all Indian tribes, it was impossible to obtain a verbal description of the music. It was necessary to record songs, study the records, and question the people concerning them. The first song recorded was about seven minutes in duration. When it was finished the chief was asked to explain the words. These words were highly poetic and contained an entire narrative, working up to a climax and

FIG. 123.—James Perry blowing conch shell trumpet.

ending in a conclusive manner. The song related that a group of young girls walked among the bright flowers, a young man appeared, and later was shot by a jealous rival. Another song was requested and the chief sang of a race between several canoes (dugouts) equipped with sails. In this song a storm arose, followed by a calm and a favoring breeze, the song ending with the wedding of the captain who won the race, while the sailors danced at the wedding. From these examples it was evident that the words of Tule songs afforded as much pleasure as the melody.
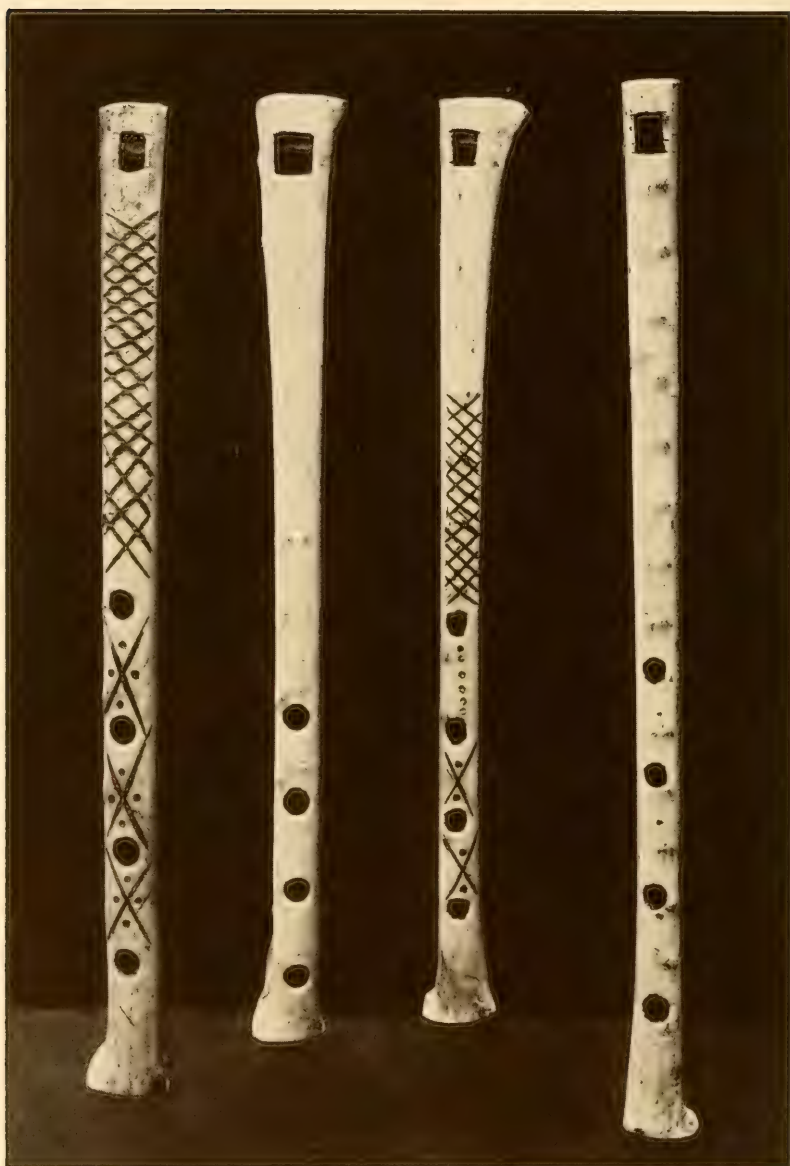
Fig. 124.—Whistles made of wing-bones of pelican and buzzard.

The chief was asked whether his people used music in the treatment of the sick, and he responded with a song for the cure of headache, containing the following words:

> I bring sweet-smelling flowers and put them in water,
> I dip a cloth in the water and put it around your head,
> Then I bring a comb, part your hair smoothly and make it pretty.
> Everyone comes to see you get better,
> And I tell you that you will never be cold again.
> Go to sleep and dream of many animals, mountain-lions and sea-lions,
> You will talk with them and understand what they say,
> When you wake you will be a doctor, like me.

It was said that a doctor " received his songs in dreams," and sang when preparing his most difficult remedies. He did not shake a rattle, nor make any commotion when treating a sick person, as is frequently done by the Indians of North America. The chief expressed the opinion this would increase the illness of the patient.

Certain songs were sung after the death of a man, and in these songs the man's spirit was directed on its way to a " happy place." Such a song was recorded and may be summarized as follows; in this portion of the song the sick man speaks to his wife.

> The fever returns. I drink the medicine and throw it on my body.
> The fever grows worse. I am going to die.
> My breath grows difficult, my face is pale,
> The medicine does not help me. I am going to die.
> Talk to my two children about me, after I am gone.
> I leave the cocoanut farm for my children.
> After I die you will go to the cocoanut farm and take the children with you,
> There you will think of me.
> If people go to our cocoanut farm and cut the trees
> You must track them and find who did it.
> I am leaving the plantain farm.
> There will be plenty of property for the children.
> I leave the small fruits, the mangoes, the bananas and other fruits,
> Think of me when you gather them.

The song then mentions his skill in hunting and fishing, enumerating the results as he had named the fruits on his farms. He tells his wife to marry again in a short time, then dies, and the remainder of the song concerns the directing of his spirit on its way.

The principal social event of the Tule is a wedding, to which the people come from all the villages. They dance and sing for several days, according to the wealth of the bride's father who provides the entertainment. The writer first obtained a full and detailed account of the wedding customs, and then asked for a wedding song. When this had been recorded she asked for a translation of the words.

The reply was : " He sang just what we *told* you . He sang how the father gets the presents ready, the chief tells the people, the chief musician makes a new flute to play at the wedding, and everybody sings and dances just like we told you. He *sings* that in the *song*."

The custom of singing to secure success in games is common among the North American Indians but absent in the Tule. Descriptions of five games were obtained but it was said that games were played only by young boys. The Tule are a hard-working people, living on the islands, or keys, and cultivating ground on the main land, going thither in the early morning and returning at night. A man's wealth depends on his efforts to push back the jungle and keep it back, thus enabling trees to grow from which he can sell the fruit.

The test of a song, as recorded among the North American Indians, has been a comparison between records made at intervals by the same or other individuals. In accordance with that method of work the writer asked for a repetition of the song concerning the canoe race, after a period of a few days. On comparing the two renditions of the song there was found to be only a general resemblance in the melodies. It may be recalled that, among the North American Indians, the repetitions of a song by the same or another individ often are absolutely exact, instances having been noted in w renditions by one person at intervals of several months were ide even in pitch and tempo.

Tule songs are a form of primitive music that, it is believed, has not hitherto been described. Vocal proficiency, among the Tule, consists in improvising melodies instead of repeating them with exactness, yet songs are " learned," and each song recorded has a distinctive character. For instance, the song for relief of headache is a soothing melody, and a song concerning eight articles has a recurrent phrase when each, in turn, is mentioned. The general character of the songs is gentle and pleasing. They have a compass of three to six tones, though the melody is usually within a compass of five tones. Nine songs have been transcribed, either wholly or in part. They contain measures of two, three, five or seven beats, occurring in irregular order and probably determined by the accented syllables of the words. The songs bear no resemblance to chants but consist of short melodic phrases of equal length, each concluding with a prolonged tone. The substance of the words is established but it seems probable that the identical words are not repeated. This would be exceedingly difficult in songs of such length, and, if done, would

tend to create a rhythmic pattern in the melody, causing it also to be repeated with exactness.

The chief said that he began the study of songs when he was ten years old. The first song he learned was the first he recorded for the writer. He gave the name of the man who taught him, saying it took him a long time to learn that first song. Seven years later, this man having gone away, he went to another from whom he learned about 30 songs. First he learned miscellaneous songs, and later learned those sung when preparing medicines and treating the sick, though he is not a doctor. Recognized standards of music were further shown by the statement that certain persons were " good singers " while others " could not sing."

INSTRUMENTAL MUSIC

No drum is used by the Tule, neither do they pound upon a pole or other object. In this respect they are unique among primitive people. A neighboring tribe uses a tall wooden drum with a hide stretched across one end, but the Tule have never adopted this instrument. The statement concerning the absence of a drum was confirmed by Major H. B. Johnson, formerly a Lieutenant of the Black Watch, B. E. F., whose acquaintance with these people extends over three years. Major Johnson went to Panama with a British expedition in 1921 and became especially interested in the Tule. He was also a member of the Marsh expedition in 1924.

The musical instruments used by the Tule are the conch-shell trumpet, bone whistle, pan-pipes, flute and gourd rattle. The first named is made by piercing a mouth-hole in the tip of the shell. The only variety used in this manner is the *Casis cameo* Stm. (fig. 123). This instrument, with its far reaching tone, appears to have been used only as a signal.

Whistles are made of the wing-bone of the pelican and king buzzard. They have four finger-holes and are decorated with lines burned with a hot iron (figs. 124, 125). These, as well as the other instruments illustrated, are in the Marsh Collection at the U. S. National Museum.

The pan-pipes are made of a different, smaller reed than the flutes. A set consists of two parts, each of which has three or four reeds bound together with a cord, and the two parts are connected by a cord nine or more inches long. In the two sets under observation the shortest reed is $4\frac{1}{2}$ inches, and the longest $14\frac{1}{2}$ inches, in length. It was said that pan-pipes in the native villages frequently contain reeds

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Fig. 125.—Igwa Nigdibippi playing bone whistle.

Fig. 126.—Igwa Nigdibippi and Alfred Robinson playing pan-pipes.

two or three feet long. Such reeds would give a deep, resonant tone. The instrument has a surprisingly loud tone, resembling that of a steam calliope, though it can be played with a moderate tone. It is

Fig. 127.—Igwa Nigdibippi playing flute and rattle.

played for dancing and for "serenading the girls." Two sets are usually played together (fig. 126), one player sounding one tone and the other the next tone, alternating in this manner throughout the

performance, and improvising the melody. Only one of the Indians present in Washington was an expert player on this instrument. In order to show the full capacity of the pan-pipes he played alone, giving a performance marked by a rapid succession of high and low tones

Fig. 128.—Gourd rattles used by Tule Indians.

suggesting that on a concertina, he also gave interesting rhythms on a single tone—rhythms that might be indicated by " dots and dashes." It is probable that two expert players, at home, would show this skill and variety when playing the alternating-tone melodies above described.

FIG. 129.—Alice Perry in native costume.

The Tule flute is of a type which, it is believed, has not been observed elsewhere. It has two finger-holes but no " whistle opening " and is held inside the cavity of the mouth, possibly touching the roof

Fig. 130.—Tule women at home.

of the mouth. For this reason the term " mouth flute " seems applicable to it (fig. 127). The specimen under observation is 24½ inches long and the finger-holes are respectively 5 and 6 inches from the lower end. The pith is removed from the reed and the opening

flushed with water to remove all shreds, after which the holes are burned with a heated iron and shaped with a sharp knife. The implement used in removing the pith is the stiff quill of a tail feather of the wild turkey.

The player usually shakes a gourd rattle with his right hand, fingering the flute with his left hand. The music at weddings is provided chiefly by two flute players, each with a gourd rattle, one being the Chief Musician who is accorded great honor, while the other is his assistant. The melodies played on the flute were simple and pleasing. Dictaphone records of the music of the flute and pan-pipes were made and transcribed in musical notation. The former intrument produced the tones of the minor triad on E flat, and the latter had a compass of seven tones. In one instance the melody played on the pan-pipe was based on G flat, and in another it was based on G.

The gourd rattle of the Tule is of the usual type, a round gourd being pierced by a stick which forms the handle, but differs from the rattle of North American tribes in that the gourd is often fastened to the handle by a cord that passes through it (fig. 128). Two types of gourd rattle are in use, one by the men and the other by the women. The former, used in connection with the flute, is not large in size but contains rather heavy pebbles. The latter is of two sorts, one being used by the women when dancing and the other " to put the babies to sleep." Information concerning these rattles was given by Alice Perry (fig. 129). The woman's dancing rattle contains many small pebbles, one being shown as the large, decorated rattle in the accompanying illustration. The second named is a smaller rattle (in the illustration) and contains numerous small pebbles and one rather large pebble. When this rattle is shaken the first resultant sound is that of the small pebbles, this is followed by the rolling of the larger stone which, continued steadily, has a peculiarly soothing effect. The Tule, like other tribes, have songs which are sung by mothers to put the children to sleep, but this is the first instance known to the writer in which Indians use instrumental music for this purpose.

The native dress of the women, with a glimpse of native environment, is shown in figure 130, a picture taken ten or more years ago. Attention is directed to the heavy necklaces of silver coins and the armlets and anklets of beads. The cotton tunics are decorated with appliqué designs of material in a contrasting color, the work being done with neatness.

RESEARCHES ON THE BURTON MOUND AND ON THE KIOWA INDIANS

The beginning of the year found Mr. John P. Harrington, ethnologist, engaged in the excavation of the principal village of the Santa Barbara Indians, known to them as Syujtun, to the early Spaniards as El Puerto de Santa Bárbara, and in more modern times as the Burton Mound. The great mound which marks the site is situated on the Santa Barbara waterfront, a block west of the principal wharf, on property now belonging to Mr. Ole Hanson and to Mr. Charles Frederick Eaton. The old village site has always been the most prominent feature of the Santa Barbara beach, and is most famous in Santa Barbara Indian and Spanish history, but had never been excavated to any extent previous to the present work.

The great village of Syujtun was mentioned four times in the Cabrillo account of 1542. Father Crespi writing in 1769 mentions its population as comprising 500 souls. With the establishment of the Santa Barbara Mission in 1782 the inhabitants were removed to the adobe cuarteles provided for them at the mission. The mound became the " beach ranch " of the Franciscans, later the site of the ranch house of Joseph Chapman, and more recently the property of Lewis T. Burton. In 1901 Mr. Milo M. Potter built a large hotel on the mound. In 1921 the hotel, which had been purchased by the Ambassador Hotel Corporation, burnt, thus releasing the site again for scientific study. Through the kind offices of Mr. George G. Heye, director of the Museum of the American Indian, money was raised for excavation of the mound by joint arrangement with the Bureau of American Ethnology.

The results of the excavation of the Indian town of Santa Barbara proved rich and interesting beyond expectation. The collection, which comprises more than seven thousand specimens, includes many large and showy pieces, such as steatite ollas, mortars and metates. Some of the graves were lined with slabs trimmed from the bones of whales. Quantities of the mother-of-pearl pendants and ornaments of the Indians were obtained, as well as shell beads of many types. The bodies were mostly in crouched position with the head to the north. In addition to the cemetery, many old wigwam sites were explored and the outline of the whole settlement slowly and laboriously traced. In the reef rock or coquina layer of the lower levels of the mound were found embedded two skeletons which have been reported upon by Dr. Bruno Oetteking, Physical Anthropologist of the Museum of

FIG. 131.—Santa Barbara, California, in 1828, showing the Burton Mound in the foreground (directly back of ship). Earliest extant picture of Santa Barbara.

FIG. 132.—The Burton Mound in 1897. (Painting by Alexander F. Harmer.)

the American Indian, and on which further studies are now in prog-
ress. The coast of California has undoubtedly been inhabited con-
tinuously for a long period, and the mound forms one of the best
monuments for the study of a stable Indian culture. Associated with
Mr. Harrington in this work are Professor D. B. Rogers, formerly
of the University of Kansas, and Mr. G. W. Bayley.

At the beginning of February Mr. Harrington returned to Washing-
ton, D. C. On April 15 opportunity was afforded for further study
of the Kiowa tribe by the coming to Washington of Eimhâ'ä (Delos

FIG. 133.—Metacarpal needles from Burton Mound. These occur ready-made,
except for boring and rounding the head, in the fetlock of the California mule
deer. One of the most unique discoveries among the artifacts.

K. Lonewolf), adopted son of the former head chief of the tribe, and
Seitmânte[n] (George Hunt), one of the chief men of the tribe. Work
with them was continued until May 21, yielding a great mass of
ethnological and mythological material.

The true inner history of the suppression of the Kato or Sun Dance
of the Kiowa was secured. The ethnological data of Mooney's Cal-
endar History of the Kiowas were corrected. The myths obtained
are without exception pretty and well told. They are as follows:

(1) The Seven Star Girls. This myth accounts for the huge pillar
of rock known as the Devil's Tower, 20 miles southeast of Sun Dance,

FIG. 134.—Eimhâ'ä, "Rescuer" (Delos K. Lonewolf), Kiowa informant.

FIG. 135.—Seitmânte", "Bear Paw" (George Hunt), Kiowa informant.

Wyoming, and takes us back to the ancient period when the Kiowa held the Black Hills. The girls became the Pleiades. (2) Seindei (the culture hero) Jumps across the Missouri River. (3) Seindei and the Bear. (4) Seindei and the Quails. (5) Seindei and the Four Pemmican Brothers. (6) Seindei Meets Whirlwind Girl. (7) Seindei Invites the Woodpeckers. (8) How Crow Became Black. (9) The Loosing of the Buffaloes. A remarkable story of how Seindei visits the keeper of the buffaloes. (10) Seindei and the Prairie Dogs. (11) Seindei and Coyote. (12) Seindei and the Rabbit. (13) Seindei and the Turkey. (14) Seindei and the Mountain Ghosts. Seindei induced the Mountain Ghosts to take out their hearts and to lay them in a pile when they visited a place where they were likely to become scared. In this way he eliminated these powerful demons from the earth.

Old hunting and fighting stories were also obtained, including a long account of a raid in Mexico.

ETHNOLOGICAL RESEARCHES AMONG THE FOX INDIANS, IOWA

Dr. Michelson left Washington towards the close of May and proceeded to Tama, Iowa, to renew his researches among the Fox (Meskwakie) Indians. He devoted especial attention to the various gens festivals, for example, the White Wolf Dance of the War Gens. Some texts on a number of sacred packs were translated. A good deal of general ethnology was obtained in both syllabary texts and translations. Some of this included the regulations of various gentes and societies. Additional information on the White Buffalo Dance and mortuary customs and beliefs was secured in time to be incorporated in the 40th Annual Report of the Bureau of American Ethnology (now in galley-proof). In his spare time Dr. Michelson gathered quite a little Winnebago and Potawatomi ethnological data from the small group of each of these tribes which habitually stays at Tama with the Fox. The data on the first largely corroborates that given by Dr. Radin in the 37th Annual Report of the Bureau of American Ethnology, and in some instances supplements it. The data on the Potawatomi is important as showing that among this tribe there are close correspondents to the Fox gens festivals. Towards the close of June Dr. Michelson returned to Washington.

A brief explanation of some of the ethnological data in the preceeding paragraph may not be inappropriate. The Foxes are organized in a number of exogamic totemic groups. These groups are named after animals for the most part, e. g., Bear, Wolf, Eagle. Male

members of these groups had a special hair-cut, appropriate only to their own groups. Personal names showed to which group the owner belonged; however, occasionally a person might be named

Fig. 136.—Fox mat of rushes, used for exterior of wigwams, etc., being made by Mrs. Charley Keyosatuck. (Photograph by Michelson.)

by another than his or her father; in this case the person would have a personal name appropriate to the gens of the namer, but would belong to the gens of his or her father unless it had been stipulated at the time that the person should belong to the gens of the namer.

These various gentes owned one or more sacred packs (not to be confused with individual personal packs) connected with an appropriate ritual and dance; also they had special songs to be sung the night

Fig. 137.—Fox bag made of bass-wood, in the process of construction
(Photograph by Michelson.)

preceding the burial of the dead, and one or two special features in burial customs. At least two possessed definite paints appropriate to themselves (Bear gens, green paint; War gens, red paint). Some of these gentes had subdivisions, and in such cases one of the sub-

divisions ranked higher than the other or others. Thus the Bear gens is composed of the Black Bears and Yellow (Brown) Bears; the tribal chieftainship was in the Black Bear division of Bear gens. This is why some Fox Indians objected to Pushitoniqua (the last chief recognized by the federal government), because he was of the wrong division of the Bear gens. The sacred packs were used especially in war. With appropriate songs and rituals one could become invisible; the bullets of the foe would not hit their mark; wide rivers would become narrow so one could retreat if hard pressed by the foe; etc. The packs are supposed to be acquired by fasting in the wilderness when various manitous would take pity on those fasting and bestow blessings.

FIG. 138.—Fox bark-house of elm. Harry Lincoln is standing at the door-way. (Photograph by Michelson.)

PROVISIONAL SOLAR-CONSTANT VALUES, AUGUST, 1920, TO NOVEMBER, 1924

BY

C. G. ABBOT AND COLLEAGUES

(PUBLICATION 2818)

PROVISIONAL SOLAR-CONSTANT VALUES, AUGUST, 1920, TO NOVEMBER, 1924 [1]

By C. G. ABBOT AND COLLEAGUES [2]

The Smithsonian Institution has employed the appropriations made by Congress for the support of the Astrophysical Observatory to continue observations of the solar constant of radiation. This means, in other words, the intensity of the sun's heat as it would be found in free space at the earth's mean solar distance. Though called the " solar constant," we find the sun's output of radiation really variable. A growing interest is apparent among scientific men and the public generally in these observations. They are held by many to offer promise of usefulness, in connection with weather reports, for the study of the dependence of weather and climates on the variations of the solar radiation.

As the variation of the sun is seldom large, there is great difficulty in maintaining a sufficiently high standard of accuracy in the solar measurements to give the magnitudes of the changes closely enough for these purposes. It is true that our investigations have indicated an extreme range of solar-constant values of 10 per cent or even more, but as Professor Marvin has pointed out, the apparent range of results has somewhat diminished as we have improved our methods. For several years the extreme range has not often exceeded 5 per cent. The well-supported march of daily values frequently indicates solar changes of 1, 2, or 3 per cent, but larger changes than these are so infrequent as to be looked upon as exceptional. One notable case of a change of 6 per cent occurred in March, 1920, accompanying the immense sun-spot group which appeared then.

Situated as the observer must be, underneath an atmosphere loaded with dust, water vapor, and other variable constituents, it would be impossible to follow solar changes as small as 1 per cent unless the

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[1] With Monthly and Decade Means from 1918.

[2] At present, Messrs. L. B. Aldrich and F. A. Greeley at Montezuma; Messrs. A. F. Moore and H. B. Freeman at Harqua Hala; Mr. F. E. Fowle, Miss M. A. Neill and Mrs. A. Bond at Washington. During the interval, January, 1921, to December, 1922, the Montezuma station was occupied by L. H. Abbot and P. E. Greeley.

most favorable localities were chosen for the observatories. Our own country does not afford the best localities in the world for this purpose, for clouds and other variable atmospheric conditions are objectionably prevalent even in our great southwestern deserts. Since October, 1920, Mount Harqua Hala, in Arizona, has been continuously occupied by us for the solar radiation work which before that date was carried on during part of each year at Mount Wilson, California.

Fortunately, the Institution was able to devote to the work the income of a portion of the Hodgkins fund, and therewith established in 1918 another station near Calama, in the nitrate desert of Chile, in South America. Our experience recommends this region very highly for the purpose. But the combined support of Congressional appropriations and the Hodgkins income would have been insufficient to maintain these two stations in the United States and Chile had not Mr. John A. Roebling, of Bernardsville, N. J., helped in the work very generously. By his advice and assistance, the Calama station was removed in August, 1920, to Mount Montezuma, nearly 10,000 feet high and about 12 miles from Calama.

Mr. Roebling has not only provided many expensive comforts and necessities for both stations, borne the heavy costs of transporting observers, and supplemented their meager compensations to enable them to bear the sacrifices involved in years of isolation, but he has also engaged Mr. H. H. Clayton (with assistants) for the past two years in the study of the effects of solar changes on weather and climate. To promote this investigation, Mr. Roebling has provided means for daily telegraphic advices from each observatory to the Smithsonian Institution, and for telegraphing the mean values to Mr. Clayton for his studies.

In this way experimental forecasts have been prepared by Mr. Clayton and communicated in advance to the Smithsonian Institution so as to make possible an unbiased test of the value, if any, of knowledge of solar changes for weather forecasting. As the results of these experiments are soon to be published by Mr. Clayton, they need not be mentioned here, further than to say that they are of high interest and promise.

The daily telegrams from both stations, required for Clayton's forecasts, called attention so sharply to all discrepancies, that we found it necessary to make several extensive investigations of sources of error, methods of reduction, etc. These investigations are not yet finished. We believe, however, that future modifications which may result from

the completion of them will not change much the relative daily values we are about to give. It is possible that there may be found a necessity to alter the general scale of the results slightly to make them comparable to our previous publications.

We would have preferred not to make public any provisional values. But the demands for recent results have become so insistent and numerous that we believe it will be better to publish briefly at this time the best knowledge we now have. The reader must understand distinctly that small modifications will probably be made in the final publication which we hope to make sometime in Volume V of the Annals of the Astrophysical Observatory.

Table 1 gives a summary of the results from Mt. Harqua Hala and Montezuma. A part of these results was published in the Monthly Weather Review for February, 1923. There were certain of them which needed correction, and so it seemed best to gather in one place all of the values determined since the publication of Volume IV of the Annals. Column 1 gives consecutive dates. Columns 2 and 5 give the numbers of observations at Harqua Hala and Montezuma respectively. Columns 3 and 6 give the weighted mean values; columns 4 and 7, their grades; and columns 8 and 9, the general weighted mean and its grade.

All of the individual determinations entering into the mean values have been slightly corrected by general formulae based on extensive statistical treatments suitable to eliminate vestiges of atmospheric influences not entirely removed by the preliminary reductions. We shall omit here the description of these statistical investigations, as they are too extensive for brief presentation. They will appear in Volume V of the Annals of the Astrophysical Observatory. We may remark, however, that except for slight horizontal corrections to scale, the methods employed are such as to leave the two stations essentially independent up to the last combination into the general mean given in column 8.

In choosing the best value for the general mean, we have been inclined to give greater weight to the better station, Montezuma. We have also been influenced by the view that sporadic values, quite out of the line of march indicated by values on either side of them, are apt to be erroneous. Finally, we have availed ourselves of the notes as to sky and instrumental conditions in forming our views as to the best value and its grade. Four grades are given, S, S−, U+, and U, meaning satisfactory, nearly satisfactory, rather unsatisfactory, and unsatisfactory. In what follows we omit all results marked U, and merely include them in table 1 for the sake of completeness.

During the month of January, 1923, there were certain changes of apparatus and methods of reduction introduced at Montezuma. In connection therewith occurred some uncertainties not yet fully understood. This has caused us to omit some of these values from Montezuma. During the summer months at Harqua Hala, there have also been many days when haziness and thunder-storm conditions have led to such uncertainties as to cause us to omit them. With these explanations, we proceed to give table 1.

TABLE I.—*Daily Solar-Constant Values*

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1920								
Aug. 1	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....
3	....	....	....	3	1.905	S	....	....
4	....	....	....	5	1.935	S	....	....
5	....	....	....	4	1.925	S	....	....
6	....	....	....	1	1.962	S—	....	....
7	....	....	....	4	1.933	S	....	....
8	....	....	....	2	1.922	S—	....	....
9	....	....	....	3	1.937	S	....	....
10	....	....	....	2	1.922	S—	....	....
11	....	....	....	3	1.925	S	....	....
12	....	....	....	4	1.908	S	....	....
13	....	....	....	4	1.918	S	....	....
14	....	....	....	1	1.921	S—	....	....
15	....	....	....	2	1.920	S—	....	....
16	....	....	....	....	....	....	....	....
17	....	....	....	4	1.932	S	....	....
18	....	....	....	2	1.943	S—	....	....
19	....	....	....	3	1.940	S	....	....
20	....	....	....	4	1.934	S	....	....
21	....	....	....	4	1.930	S	....	....
22	....	....	....	2	1.945	S	....	....
23	....	....	....	4	1.942	S	....	....
24	....	....	....	2	1.901	S—	....	....
25	....	....	....	....	....	....	....	....
26	....	....	....	2	1.945	S	....	....
27	....	....	....	5	1.929	S	....	....
28	....	....	....	4	1.950	S	....	....
29	....	....	....	4	1.916	S	....	....
30	....	....	....	5	1.921	S	....	....
31	....	....	....	5	1.935	S	....	....
Sept. 1	....	....	....	5	1.942	S	....	....
2	....	....	....	5	1.947	S	....	....
3	....	....	....	2	1.952	S	....	....
4	....	....	....	....	....	....	....	....
5	....	....	....	2	1.936	U+	....	....
6	....	....	....	5	1.967	S	....	....
7	....	....	....	5	1.946	S	....	....
8	....	....	....	5	1.967	S	....	....
9	....	....	....	4	1.945	S	....	....
10	....	....	....	5	1.959	S	....	....
11	....	....	....	2	1.926	S	....	....
12	....	....	....	4	1.943	S	....	....
13	....	....	....	4	1.940	S	....	....
14	....	....	....	5	1.950	S	....	....
15	....	....	....	2	1.961	S—	....	....
16	....	....	....	5	1.950	S	....	....
17	....	....	....	5	1.950	S	....	....
18	....	....	....	4	1.947	S	....	....
19	....	....	....	2	1.932	S	....	....
20	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....
22	....	....	....	3	1.937	S	....	....
23	....	....	....	1	1.961	S	....	....
24	....	....	....	5	1.958	S	....	....
25	....	....	....	4	1.944	S—	....	....
26	....	....	....	3	1.939	S	....	....
27	....	....	....	1	1.914	S—	....	....
28	....	....	....	4	1.956	S—	....	....
29	....	....	....	....	....	....	....	....
30	....	....	....	....	....	....	....	....

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1920								
Oct 1	....	....	....	4	1.943	S—	1.943	S—
2	....	....	....	4	1.928	S	1.928	S
3	....	....	....	....	....	....	....	....
4	2	1.942	S	4	1.952	S	1.946	S
5	2	1.981	U	4	1 957	S	1.957	S
6	....	....	....	4	1.929	S	1.929	S
7	....	....	....	2	1.917	S—	1.917	S—
8	2	1.952	S	2	1.942	S—	1.947	S
9	....	....	....	2	1.959	S	1.959	S
10	2	1.935	U	2	1.947	S—	1.947	S—
11	....	....	....	4	1.956	S	1.956	S
12	1	1.980	U	3	1.943	S—	1.943	S—
13	2	1.891	U	....	....	....	....	....
14	3	1.949	S	....	....	....	1.949	S
15	3	1.971	S	3	1.954	S	1.963	S
16	3	1.947	S	5	1.958	S	1.953	S
17	....	....	....	3	1.944	S—	1.944	S—
18	2	1.955	S—	3	1.942	S—	1.948	S—
19	....	....	....	....	....	....	....	....
20	....	....	....	....	....	....	....	....
21	1	1.971	U	4	1.951	S—	1.951	S—
22	3	1.935	S	2	1.945	S	1.940	S
23	2	1.933	S	....	....	....	1.933	S
24	3	1.916	S—	....	....	....	1.916	S—
25	3	1.914	S	1	1.954	U	1.934	S—
26	3	1.955	S	....	....	....	1.955	S
27	....	....	....	....	....	....	....	....
28	....	....	....	3	1.942	S—	1.942	S—
29	....	....	....	4	1.954	S	1.954	S
30	....	....	....	2	1.931	S—	1.931	S—
31	....	....	....	2	1.923	S	1.923	S
Nov. 1	....	....	....	4	1.960	S	1.960	S
2	3	1.931	S	2	1.956	S	1.943	S
3	3	1.976	S	2	1.956	S	1.966	S
4	....	....	....	2	1.952	S—	1.952	S—
5	1	1.963	U	4	1.950	S	1.954	S
6	....	....	....	3	1.948	S	1.948	S
7	....	....	....	2	1.945	S—	1.945	S—
8	3	1.955	S	2	1.950	S	1.952	S
9	....	....	....	3	1.947	S	1.947	S
10	3	1.956	S—	3	1.949	S—	1.952	S
11	....	....	....	3	1.955	S	1.955	S
12	....	....	....	2	1.938	S—	1.938	S—
13	2	1.950	S	4	1.950	S	1.950	S
14	2	1.966	S—	2	1.942	S	1.953	S
15	....	....	....	5	1.953	S	1.953	S
16	2	1.934	S—	2	1.925	S—	1.929	S
17	2	1.949	S—	2	1.964	S—	1.956	S
18	2	1.961	S—	3	1.942	S	1.951	S—
19	....	....	....	....	....	....	....	....
20	1	1.999	U	....	....	....	....	....
21	1	1.926	S—	1	1.957	S—	1.941	S—
22	....	....	....	2	1.945	S—	1.945	S—
23	....	....	....	2	1.956	S	1.956	S
24	....	....	....	2	1.935	S	1.935	S
25	....	....	....	2	1.949	S—	1.949	S—
26	....	....	....	2	1.938	S—	1.938	S—
27	....	....	....	2	1.938	S—	1.938	S—
28	....	....	....	....	....	....	....	....
29	....	....	....	....	....	....	....	....
30	....	....	....	....	....	....	....	....

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1920								
Dec. 1	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....
3	....	....	....	2	1.944	S	1.944	S
4	....	....	....	2	1.966	S	1.966	S
5	....	....	....	4	1.955	S	1.955	S
6	....	....	....	3	1.959	S—	1.959	S—
7	....	....	....	3	1.954	S	1.954	S
8	....	....	....	4	1.959	S	1.959	S
9	....	....	....	....	....	....	....	....
10	....	....	....	3	1.965	S—	1.965	S—
11	....	....	....	4	1.977	S	1.977	S
12	....	....	....	2	1.959	S	1.959	S
13	....	....	....	3	1.957	S—	1.957	S—
14	....	....	....	3	1.946	S	1.946	S
15	2	1.957	S—	4	1.949	S	1.953	S
16	....	....	....	2	1.953	S	1.953	S
17	1	1.907	U	2	1.962	S	1.962	S
18	....	....	....	2	1.954	S	1.954	S
19	2	1.916	U+	2	1.959	S—	1.959	S—
20	....	....	....	2	1.950	S	1.950	S
21	2	1.886	U	....	....	....	....	....
22	....	....	....	1	1.962	S—	1.962	S—
23	....	....	....	....	....	....	....	....
24	....	....	....	....	....	....	....	....
25	....	....	....	1	1.944	S—	1.944	S—
26	....	....	....	....	....	....	....	....
27	....	....	....	....	....	....	....	....
28	3	1.925	U+	....	....	....	1.925	U+
29	....	....	....	....	....	....	....	....
30	3	1.957	S	2	1.954	S	1.956	S
31	3	1.955	S	2	1.966	S	1.960	S
1921								
Jan. 1	3	1.957	S	....	....	....	1.957	S
2	....	....	....	....	....	....	....	....
3	....	....	....	....	....	....	....	....
4	....	....	....	2	1.968	S -	1.968	S—
5	....	....	....	2	1.964	S—	1.964	S—
6	....	....	....	3	1.931	S	1.931	S
7	....	....	....	2	1.954	S	1.954	S
8	3	2.021	S	2	1.954	S	1.987	S—
9	....	....	....	....	....	....	....	....
10	3	2.000	S	1	1.968	S	1.984	S—
11	....	....	....	....	....	....	....	....
12	3	1.943	S	....	....	....	1.943	S
13	3	1.969	S	....	....	....	1.969	S—
14	3	1.975	S	1	1.964	S —	1.970	S
15	....	....	....	2	1.962	S	1.962	S
16	1	1.968	U+	....	....	....	1.968	U+
17	....	....	....	....	....	....	....	....
18	....	....	....	1	1.932	S—	1.932	S—
19	3	2.010	U	....	....	....	....	....
20	1	1.949	U	....	....	....	1.949	U
21	1	1.948	U	....	....	....	1.948	U
22	....	....	....	....	....	....	....	....
23	....	....	....	....	....	....	....	....
24	3	1.960	S—	....	....	....	1.960	S—
25	1	1.960	U	....	....	....	1.960	U
26	....	....	....	....	....	....	....	....
27	....	....	....	....	....	....	....	....
28	....	....	....	....	....	....	....	....
29	3	1.944	S—	....	....	....	1.944	S—
30	....	....	....	....	....	....	....	....
31	1	1.940	S—	....	....	....	1.940	S—

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1921								
Feb. 1	3	1.923	S	....	....	....	1.923	S
2	2	1.964	S—	....	....	....	1.964	S—
3	1	1.943	S—	....	....	....	1.943	S—
4	1	1.852	U	....	....	....	....	....
5	....	....	....	....	....	....	....	....
6	1	1.940	S—	....	....	....	1.940	S—
7	....	....	....	....	....	....	....	....
8	3	1.940	S	....	....	....	1.940	S
9	....	....	....	....	....	....	....	....
10	1	2.011	U	....	....	....	....	....
11	3	1.958	S	2	1.956	S—	1.957	S
12	2	1.985	S—	1	1.947	S—	1.966	S—
13	3	1.960	S	....	....	....	1.960	S
14	1	1.893	U	....	....	....	....	....
15	3	1.960	S	....	....	....	1.960	S
16	3	1.961	S	....	....	....	1.961	S
17	3	1.955	S	....	....	....	1.955	S
18	3	1.948	S—	....	....	....	1.948	S—
19	3	1.926	S	....	....	....	1.926	S
20	1	1.932	U	....	....	....	1.932	U
21	....	....	....	2	1.959	S—	1.959	S—
22	3	1.948	S	....	....	....	1.948	S
23	3	1.943	S—	....	....	....	1.943	S—
24	3	1.941	S	2	1.946	S	1.944	S
25	3	1.953	S	2	1.960	S	1.957	S
26	....	....	....	2	1.955	S	1.955	S
27	....	....	....	....	....	....	....	....
28	....	....	....	2	1.972	S—	1.972	S—
Mar. 1	2	1.969	U+	2	1.963	S—	1.966	S
2	3	1.942	S	1	1.954	S—	1.948	S
3	1	1.991	U	2	1.959	S—	1.959	S—
4	2	2.007	U	2	1.956	S—	1.956	S—
5	3	1.919	U—	2	1.943	S—	1.943	S—
6	1	1.912	U	2	1.946	S—	1.946	S—
7	2	1.929	U	2	1.952	S—	1.952	S—
8	3	1.908	U	....	....	....	....	....
9	....	....	....	....	....	....	....	....
10	....	....	....	1	1.957	S—	1.957	S—
11	....	....	....	....	....	....	....	....
12	....	....	....	....	....	....	....	....
13	....	....	....	1	1.949	S—	1.949	S—
14	....	....	....	1	1.868	U	....	....
15	....	....	....	....	....	....	....	....
16	3	1.959	S—	....	....	....	1.959	S—
17	3	1.913	S	2	1.950	S—	1.925	S—
18	....	....	....	2	1.915	S	1.915	S
19	1	1.998	U	2	1.948	S—	1.948	S—
20	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....
22	1	2.003	U	....	....	....	....	....
23	3	1.940	S—	....	....	....	1.940	S—
24	2	1.881	U	....	....	....	....	....
25	1	1.878	U	....	....	....	....	....
26	1	1.946	U	....	....	....	....	....
27	3	1.920	S—	....	....	....	1.920	S—
28	3	1.940	S—	....	....	....	1.940	S—
29	3	1.959	S—	....	....	....	1.959	S—
30	....	....	....	....	....	....	....	....
31	3	1.951	S	....	....	....	1.951	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1921								
Apr. 1	....	....	....	2	1.948	S—	1.948	S—
2	....	....	....	1	1.957	S—	1.957	S—
3	....	....	....	....	....	....	....	....
4	....	....	....	....	....	....	....	....
5	....	....	....	1	1.965	S—	1.965	S—
6	3	1.928	S	1	1.953	S—	1.940	S—
7	3	1.936	S	....	....	....	1.936	S
8	2	1.872	U	2	1.950	S	1.950	S
9	1	1.894	U	2	1.950	S—	1.950	S—
10	3	1.957	S	2	1.931	S—	1.944	S—
11	....	....	....	....	....	....	....	....
12	1	1.933	S—	3	1.922	S	1.927	S
13	....	....	....	....	....	....	....	....
14	....	....	....	2	1.956	S—	1.956	S—
15	3	1.945	S	2	1.947	S—	1.946	S
16	....	....	....	2	1.946	S—	1.946	S
17	3	1.953	S	2	1.952	S—	1.952	S
18	....	....	....	2	1.945	S—	1.945	S—
19	....	....	....	2	1.920	S—	1.920	S—
20	2	1.968	S—	....	....	....	1.968	S—
21	....	....	....	1	1.921	S—	1.921	S—
22	3	1.956	S	....	....	....	1.956	S
23	2	1.919	S	....	....	....	1.919	S
24	2	1.933	S—	....	....	....	1.933	S—
25	2	1.947	U+	1	1.946	S—	1.946	S—
26	2	1.944	S—	....	....	....	1.944	S—
27	2.	1.988	S—	....	....	....	1.988	S—
28	2	1.951	S—	....	....	....	1.951	S—
29	2	1.962	S—	....	....	....	1.962	S—
30	2	1.945	S—	....	....	....	1.945	S—
May 1	1	1.958	S—	....	....	....	1.958	S—
2	1	1.950	S	....	....	....	1.950	S
3	1	1.947	S—	2	1.946	S—	1.946	S
4	....	....	....	2	1.950	S	1.950	S
5	....	....	....	1	1.933	S—	1.933	S—
6	....	....	....	2	1.950	S	1.950	S
7	....	....	....	....	....	....	....	....
8	1	1.963	U	2	1.955	S	1.955	S
9	1	1.972	U	2	1.944	S	1.944	S
10	1	1.962	U+	....	....	....	1.962	U+
11	....	....	....	....	....	....	....	....
12	1	1.948	S—	....	....	....	1.948	S—
13	1	1.964	S—	....	....	....	1.964	S—
14	1	1.893	U	2	1.941	S	1.941	S
15	2	1.929	S—	2	1.937	S	1.934	S
16	2	1.938	S—	....	....	....	1.938	S—
17	....	....	....	....	....	....	....	....
18	3	1.957	S	....	....	....	1.957	S
19	3	1.963	S	....	....	....	1.963	S
20	....	....	....	....	....	....	....	....
21	....	....	....	2	1.868	U—	....	....
22	1	2.031	U—	2	1.937	S	1.937	S
23	2	1.962	S—	2	1.935	S	1.948	S—
24	....	....	....	....	....	....	....	....
25	3	1.959	S	2	1.950	S	1.954	S
26	1	1.987	U	....	....	....	....	....
27	2	1.968	U	....	....	....	1.968	U
28	2	1.958	U	1	1.941	S—	1.941	S—
29	2	1.951	S—	....	....	....	1.951	S—
30	1	1.953	U	....	....	....	1.953	U
31	2	1.796	U—	....	....	....	....	....

TABLE 1.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1921 June 1	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....
3	....	....	....	....	....	....	....	....
4	1	1.943	S—	2	1.943	S	1.943	S
5	3	1.901	S—	....	....	....	1.901	S
6	2	1.974	U	....	....	....	....	....
7	3	1.943	S	1	1.914	S—	1.928	S—
8	2	1.938	S	2	1.938	S	1.938	S
9	2	1.947	S	5	1.938	S	1.942	S
10	2	1.910	S—	....	....	....	1.910	S—
11	2	1.922	U+	2	1.929	S	1.926	S
12	....	....	....	....	....	....	....	....
13	....	....	....	1	1.937	S—	1.937	S—
14	....	....	....	....	....	....	....	....
15	....	....	....	....	....	....	....	....
16	2	1.941	S—	....	....	....	1.941	S—
17	3	1.941	S	....	....	....	1.941	S
18	2	1.939	S—	2	1.950	S	1.945	S—
19	2	1.953	U	2	1.929	S	1.938	S—
20	2	1.962	U	1	1.933	S—	1.943	S—
21	3	1.927	S—	1	1.942	S—	1.934	S—
22	2	1.933	S	2	1.955	S—	1.944	S—
23	2	1.922	S	....	....	....	1.922	S—
24	2	1.933	S—	2	1.943	S—	1.938	S
25	3	1.945	S	2	1.940	S	1.942	S
26	2	1.946	S	2	1.941	S	1.944	S
27	3	1.922	S	2	1.940	S—	1.931	S—
28	2	1.960	S—	3	1.944	S	1.952	S
29	2	1.937	S—	2	1.952	S	1.944	S
30	2	1.906	S	....	....	....	1.906	S
July 1	3	1.915	U	3	1.939	S—	1.939	S—
2	2	1.919	U	3	1.946	S	1.946	S
3	2	1.942	S—	2	1.947	S—	1.945	S
4	2	1.891	U	....	....	....	....	....
5	2	1.943	S	....	....	....	1.943	S
6	2	1.938	S	....	....	....	1.938	S
7	2	1.920	S—	....	....	....	1.920	S—
8	2	1.937	U+	....	....	....	1.937	U+
9	1	1.921	U	2	1.959	S	1.959	S
10	1	1.948	U	3	1.964	S	1.964	S
11	....	....	....	3	1.936	S—	1.936	S—
12	....	....	....	....	....	....	....	....
13	....	....	....	2	1.951	S	1.951	S
14	....	....	....	3	1.954	S	1.954	S
15	....	....	....	1	2.017	U	....	....
16	....	....	....	....	....	....	....	....
17	2	1.945	U	....	....	....	1.945	U
18	2	1.961	U	....	....	....	1.961	U
19	2	1.928	U	....	....	....	1.928	U
20	2	1.940	U	2	1.952	S—	1.952	S—
21	2	1.936	U	3	1.959	S	1.959	S
22	2	1.952	U	3	1.951	S	1.951	S
23	1	1.962	U	....	....	....	1.962	U
24	....	....	....	....	....	....	....	....
25	2	1.938	U	2	1.951	S	1.951	S
26	2	1.920	U+	3	1.925	S	1.923	S
27	1	1.929	U	2	1.921	S—	1.925	S
28	....	....	....	1	1.955	S—	1.955	S—
29	....	....	....	2	1.949	S	1.949	S
30	....	....	....	....	....	....	....	....
31	....	....	....	1	1.938	S—	1.938	S—

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1921								
Aug. 1	2	1.938	S	4	1.935	S	1.936	S
2	....	....	....	....	....	....	....	....
3	....	....	....	....	....	....	....	....
4	....	....	....	....	....	....	....	....
5	....	....	....	....	....	....	....	....
6	....	....	....	....	....	....	....	....
7	2	1.945	S—	....	....	....	1.945	S—
8	....	....	....	....	....	....	....	....
9	2	1.916	S—	....	....	....	1.916	S—
10	2	1.937	S—	....	....	....	1.937	S—
11	1	1.951	S—	....	....	....	1.951	S—
12	2	1.946	S—	....	....	....	1.946	S—
13	....	....	....	....	....	....	....	....
14	2	1.946	S	....	....	....	1.946	S
15	3	1.943	S—	....	....	....	1.943	S—
16	1	1.947	S—	....	....	....	1.947	S—
17	....	....	....	....	....	....	....	....
18	....	....	....	....	....	....	....	....
19	....	....	....	....	....	....	....	....
20	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....
22	....	....	....	....	....	....	....	....
23	1	1.948	U	....	....	....	....	....
24	2	1.948	U	....	....	....	1.948	U
25	1	1.941	U	....	....	....	....	....
26	....	....	....	....	....	....	....	....
27	....	....	....	....	....	....	....	....
28	1	1.919	S—	....	....	....	1.919	S—
29	....	....	....	....	....	....	....	....
30	3	1.913	S—	....	....	....	1.913	S—
31	3	1.938	U	....	....	....	....	....
Sept. 1	3	1.933	S	....	....	....	1.933	S
2	2	1.929	S—	....	....	....	1.929	S—
3	3	1.942	S	....	....	....	1.942	S
4	2	1.941	S	....	....	....	1.941	S
5	3	1.940	S	....	....	....	1.940	S
6	3	1.936	S	....	....	....	1.936	S
7	3	1.943	S	....	....	....	1.943	S
8	2	1.935	S—	....	....	....	1.935	S—
9	2	1.951	S	....	....	....	1.951	S
10	3	1.952	S	....	....	....	1.952	S
11	2	1.953	S—	....	....	....	1.953	S—
12	2	1.947	S—	....	....	....	1.947	S—
13	2	1.949	S—	....	....	....	1.949	S—
14	3	1.952	S	....	....	....	1.952	S
15	2	1.944	S—	....	....	....	1.944	S—
16	2	1.941	S—	....	....	....	1.941	S—
17	3	1.946	S	....	....	....	1.946	S
18	2	1.950	S	....	....	....	1.950	S
19	3	1.943	S	....	....	....	1.943	S
20	3	1.945	S	....	....	....	1.945	S
21	2	1.946	S	....	....	....	1.946	S
22	....	....	....	....	....	....	....	....
23	1	1.946	U	....	....	....	1.946	U
24	3	1.942	S—	1	1.937	S—	1.939	S
25	2	1.928	S—	2	1.965	S	1.946	S—
26	3	1.936	S	....	....	....	1.936	S
27	3	1.939	S	3	1.954	S	1.947	S
28	....	....	....	3	1.953	S	1.953	S
29	....	....	....	....	....	....	....	....
30	....	....	....	5	1.955	S	1.955	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
	Harqua Hala			Montezuma			General mean	
1921								
Oct. 1	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....
3	3	1.961	S	4	1.930	S	1.945	S—
4	1	1.934	U+	4	1.959	S	1.946	S
5	2	1.932	S	4	1.938	S	1.935	S
6	....	....	....	2	1.960	S	1.960	S
7	3	1.949	S	4	1.952	S	1.951	S
8	2	1.936	S—	3	1.932	S	1.934	S
9	3	1.937	S	2	1.929	S	1.933	S
10	3	1.938	S	1	2.023	U	1.938	S—
11	2	1.933	U	....	....	....	1.933	U
12	2	1.933	U	....	....	....	1.933	U
13	....	....	....	2	1.944	S—	1.944	S—
14	2	1.925	U	....	....	....	....	....
15	3	1.933	S	....	....	....	1.933	S
16	2	1.945	S—	1	1.962	S—	1.953	S—
17	1	1.937	U	....	....	....	1.937	U
18	2	1.937	S—	1	2.001	U	1.937	S—
19	3	1.947	S	....	....	....	1.947	S
20	1	1.959	S—	....	....	....	1.959	S—
21	3	1.934	S	....	....	....	1.934	S
22	1	1.927	U	1	1.938	S	1.938	S
23	....	....	....	3	1.962	S	1.962	S
24	....	....	....	....	....	....	....	....
25	1	1.942	U	....	....	....	1.942	U
26	3	1.952	S	....	....	....	1.952	S
27	3	1.946	S—	....	....	....	1.946	S—
28	1	1.962	S—	....	....	....	1.962	S—
29	3	1.955	S	....	....	....	1.955	S
30	2	1.962	S—	....	....	....	1.962	S—
31	2	1.957	S	....	....	....	1.957	S
Nov. 1	2	1.949	S—	....	....	....	1.949	S—
2	3	1.955	S	....	....	....	1.955	S
3	2	1.943	S—	....	....	....	1.943	S—
4	2	1.946	S—	3	1.952	S	1.949	S
5	....	....	....	....	....	....	....	....
6	....	....	....	....	....	....	....	....
7	2	1.967	S—	....	....	....	1.967	S—
8	2	1.963	S—	....	....	....	1.963	S—
9	....	....	....	....	....	....	....	S—
10	2	1.956	S—	....	....	....	1.956	S—
11	1	1.961	U+	....	....	....	1.961	U+
12	....	....	....	....	....	....	....	....
13	2	1.969	S	....	....	....	1.969	S
14	2	1.970	S	....	....	....	1.970	S
15	2	1.947	S	1	1.907	U	1.947	S—
16	....	....	....	1	1.944	S	1.944	S
17	....	....	....	4	1.962	S	1.962	S
18	2	1.950	S	4	1.940	S	1.945	S
19	2	1.957	S—	4	1.937	S	1.947	S
20	2	1.946	S	3	1.958	S	1.952	S
21	2	1.972	S—	4	1.955	S	1.963	S—
22	2	1.975	S—	....	....	....	1.975	S
23	2	1.956	U	3	1.932	S	1.932	S—
24	....	....	....	2	1.962	S—	1.962	S—
25	2	1.964	U	4	1.944	S	1.944	S
26	2	1.968	U	4	1.948	S	1.948	S
27	2	1.964	S—	3	1.956	S	1.960	S
28	2	1.954	S—	2	1.963	S	1.959	S
29	....	....	....	2	1.946	S	1.946	S
30	....	....	....	....	....	....	....	....

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1921								
Dec. 1	....	....	....	2	1.962	S	1.962	S
2	2	1.954	S	4	1.944	S+	1.949	S
3	2	1.923	S—	3	1.946	S	1.935	S—
4	2	1.935	S—	3	1.953	S	1.944	S
5	....	....	....	3	1.953	S	1.953	S
6	....	....	....	3	1.945	S	1.945	S
7	2	1.946	S	2	1.968	S	1.957	S
8	2	1.954	S	2	1.970	S—	1.962	S—
9	2	1.962	S	4	1.960	S	1.961	S
10	....	....	....	3	1.947	U+	1.947	U+
11	2	1.940	S—	3	1.947	S	1.944	S
12	2	1.961	S	....	....	....	1.961	S—
13	....	....	....	....	....	....	....	....
14	....	....	....	3	1.926	S	1.926	S
15	2	1.960	S—	....	....	....	1.960	S—
16	....	....	....	....	....	....	....	....
17	....	....	....	....	....	....	....	....
18	....	....	....	....	....	....	....	....
19	....	....	....	....	....	....	....	....
20	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....
22	....	....	....	....	....	....	....	....
23	1	1.956	S—	....	....	....	1.956	S—
24	....	....	....	....	....	....	....	....
25	....	....	....	....	....	....	....	....
26	....	....	....	....	....	....	....	....
27	....	....	....	....	....	....	....	....
28	....	....	....	....	....	....	....	....
29	....	....	....	....	....	....	....	....
30	1	1.940	U	....	....	....	1.940	U
31	....	....	....	....	....	....	....	....
1922								
Jan. 1	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....
3	....	....	....	....	....	....	....	....
4	2	1.931	S—	....	....	....	1.931	S—
5	1	1.941	S—	....	....	....	1.941	S—
6	....	....	....	....	....	....	....	....
7	....	....	....	....	....	....	....	....
8	....	....	....	1	1.923	S—	1.923	S—
9	1	1.928	S—	....	....	....	1.928	S—
10	1	1.945	U	....	....	....	1.945	U
11	....	....	....	2	1.932	U	1.932	U
12	2	1.937	S—	2	1.922	S—	1.929	S
13	2	1.954	S	2	1.942	S—	1.948	S
14	1	1.952	U	3	1.941	S—	1.941	S—
15	2	1.941	S	3	1.952	S	1.946	S
16	2	1.947	S	2	1.970	S	1.959	S—
17	2	1.953	U	3	1.949	S	1.949	S
18	2	1.952	U	....	....	....	1.952	U
19	....	....	....	1	1.958	S—	1.958	S—
20	2	1.938	S	1	1.936	S	1.937	S
21	2	1.940	S	1	1.959	S	1.950	S
22	2	1.946	S	1	1.941	S	1.943	S
23	....	....	....	....	....	....	....	....
24	2	1.935	U+	1	1.957	S	1.946	S—
25	2	1.937	S	1	1.927	S	1.932	S
26	2	1.943	S—	1	1.936	S	1.939	S
27	....	....	....	1	1.944	S	1.944	S—
28	2	1.916	U	1	1.951	S	1.951	S
29	....	....	....	....	....	....	....	....
30	....	....	....	1	1.987	S—	1.987	S—
31	....	....	....	1	1.959	S	1.959	S—

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1922								
Feb. 1	....	....	....	....	....	....	....	....
2	2	1.934	S	....	....	....	1.934	S
3	1	1.939	U	....	....	....	1.939	U
4	1	1.946	U	....	....	....	1.946	U
5	....	....	....	....	....	....	....	....
6	2	1.955	S—	....	....	....	1.955	S —
7	....	....	....	....	....	....	....	....
8	....	....	....	....	....	....	....	....
9	....	....	....	....	....	....	....	....
10	....	....	....	1	1.910	S—	1.910	S—
11	....	....	....	....	....	....	....	....
12	2	1.954	S	1	1.977	U	1.954	S—
13	2	1.955	S	1	1.938	S	1.946	S
14	1	1.932	U	....	....	....	1.932	U
15	....	....	....	1	1.967	S—	1.967	S—
16	2	1.958	S—	....	....	....	1.958	S—
17	2	1.947	S—	....	....	....	1.947	S—
18	2	1.952	S—	1	1.996	U	1.952	S—
19	2	1.949	U	1	1.932	S—	1.932	S—
20	2	1.948	S—	....	....	....	1.948	S—
21	....	....	....	....	....	....	....	....
22	1	1.941	U	1	1.958	S	1.958	S—
23	....	....	....	1	1.930	S	1.930	S—
24	....	....	....	1	1.969	S	1.969	S—
25	1	1.945	U	1	1.936	S	1.936	S—
26	....	....	....	....	....	....	....	....
27	....	....	....	....	....	....	....	....
28	2	1.917	U	1	1.940	S	1.940	S—
Mar. 1	2	1.912	U	....	....	....	....	....
2	2	1.944	S	1	1.874	U	1.944	S—
3	2	1.936	U	1	1.932	S—	1.932	S—
4	2	1.939	S	1	2.059	U	1.939	S—
5	2	1.909	U	....	....	....	....	....
6	2	1.933	S—	1	1.880	U	1.933	S—
7	....	....	....	1	1.965	S—	1.965	S—
8	2	1.930	S—	1	1.892	U	1.930	S—
9	2	1.888	U	....	....	....	....	....
10	2	1.920	S—	1	2.003	U	1.920	S—
11	....	....	....	1	1.963	S—	1.963	S—
12	....	....	....	1	1.947	S—	1.947	S—
13	2	1.941	S—	1	1.908	S—	1.924	S—
14	1	1.940	U	....	....	....	1.940	U
15	....	....	....	....	....	....	....	....
16	....	....	....	....	....	....	....	....
17	....	....	....	1	1.933	S—	1.933	S—
18	2	1.940	S	....	....	....	1.940	S
19	2	1.915	S	....	....	....	1.915	S—
20	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....
22	....	....	....	2	1.936	S	1.936	S—
23	2	1.878	U	3	1.943	S—	1.943	S—
24	2	1.934	S—	3	1.932	S—	1.933	S
25	....	....	....	3	1.925	S—	1.925	S—
26	2	1.905	S	....	....	....	1.905	S
27	2	1.913	S	1	1.919	S—	1.916	S
28	....	....	....	....	....	....	....	....
29	2	1.941	S—	....	....	....	1.941	S—
30	....	....	....	....	....	....	....	....
31	....	....	....	....	....	....	....	....

(14)

TABLE 1.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1922								
Apr. 1	2	1.939	S—	....	....	....	1.939	S—
2	2	1.939	S—	....	....	....	1.939	S—
3	3	1.924	S	....	....	....	1.924	S
4	....	....	....	....	....	....	....	....
5	....	....	....	3	1.929	S	1.929	S
6	....	....	....	3	1.917	S	1.917	S
7	2	1.932	S	4	1.927	S—	1.930	S
8	3	1.923	U	3	1.937	S	1.937	S—
9	....	....	....	2	1.935	S—	1.935	S—
10	2	1.921	S—	....	....	....	1.921	S—
11	2	1.918	S—	3	1.939	S	1.928	S—
12	2	1.915	S—	3	1.886	U	1.915	S—
13	2	1.934	U	1	1.995	U	....	....
14	2	1.925	S	....	....	....	1.925	S
15	3	1.912	S—	....	....	....	1.912	S—
16	2	1.937	S—	....	....	....	1.937	S—
17	2	1.924	S	....	....	....	1.924	S
18	....	....	....	2	1.935	S	1.935	S
19	2	1.910	S—	2	1.935	S	1.923	S—
20	2	1.923	S	....	....	....	1.923	S
21	....	....	....	....	....	....	....	....
22	2	1.885	U	2	1.918	S	1.918	S
23	2	1.933	S—	....	....	....	1.933	S—
24	3	1.895	U	....	....	....	....	....
25	....	....	....	....	....	....	....	....
26	2	1.914	S—	....	....	....	1.914	S—
27	3	1.864	U	....	....	....	....	....
28	2	1.907	S—	....	....	....	1.907	S—
29	....	....	....	1	1.941	S	1.941	S—
30	2	1.943	S—	2	1.912	S	1.927	S—
May 1	2	1.934	S—	....	....	....	1.934	S—
2	3	1.915	U	....	....	....	1.915	U
3	2	1.910	U	....	....	....	1.910	U
4	2	1.919	S—	....	....	....	1.919	S—
5	2	1.914	U	....	....	....	1.914	U
6	....	....	....	....	....	....	....	....
7	2	1.945	U	....	....	....	1.945	U
8	....	....	....	1	1.910	S—	1.910	S—
9	....	....	....	3	1.886	U+	....	....
10	2	1.922	U	4	1.936	S—	1.936	S—
11	3	1.931	S	3	1.922	S	1.927	S
12	2	1.931	S	2	1.932	S	1.932	S
13	2	1.934	S	....	....	....	1.934	S
14	2	1.923	S	....	....	....	1.923	S
15	2	1.942	S—	....	....	....	1.942	S—
16	3	1.945	S	....	....	....	1.945	S
17	2	1.920	S—	....	....	....	1.920	S—
18	2	1.935	S—	....	....	....	1.935	S—
19	2	1.935	S	3	1.918	U	1.935	S—
20	2	1.940	S	....	....	....	1.940	S
21	2	1.938	S	....	....	....	1.938	S
22	3	1.930	S	....	....	....	1.930	S
23	....	....	....	....	....	....	....	....
24	....	....	....	....	....	....	....	....
25	3	1.927	U	....	....	....	1.927	U
26	2	1.937	S—	....	....	....	1.397	S—
27	2	1.937	S	....	....	....	1.937	S
28	2	1.897	S	....	....	....	1.897	S
29	2	1.908	U+	....	....	....	1.908	U+
30	2	1.932	U+	....	....	....	1.932	U+
31	2	1.914	U+	....	....	....	1.914	U+

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1922								
June 1	2	1.922	S	2	1.905	S	1.913	S
2	2	1.931	S—	2	1.904	S	1.917	S—
3	3	1.943	S	2	1.919	S	1.931	S
4	2	1.933	S	....	....	....	1.933	S
5	2	1.929	S	....	....	....	1.929	S
6	3	1.940	S	....	....	....	1.940	S
7	2	1.940	S—	3	1.889	U	1.940	S—
8	2	1.942	U	....	....	....	1.942	U
9	3	1.948	S—	....	....	....	1.948	S—
10	3	1.945	S	....	....	....	1.945	S
11	1	1.941	S—	....	....	....	1.941	S—
12	....	....	....	....	....	....	....	....
13	2	1.925	U	....	....	....	1.925	U
14	2	1.921	S	1	1.905	S—	1.913	S
15	3	1.921	S	2	1.922	S	1.922	S
16	2	1.930	S	3	1.931	S—	1.930	S
17	3	1.913	S	....	....	....	1.913	S
18	2	1.910	S—	....	....	....	1.910	S—
19	2	1.895	S	1	1.890	S—	1.892	S
20	2	1.882	S	....	....	....	1.882	S
21	2	1.880	S—	....	....	....	1.880	S—
22	....	....	....	....	....	....	....	....
23	....	....	....	....	....	....	....	....
24	2	1.897	U+	....	....	....	1.897	U+
25	....	....	....	2	1.923	S—	1.923	S—
26	2	1.895	S—	....	....	....	1.895	S—
27	3	1.908	U	....	....	....	....	....
28	3	1.880	S—	....	....	....	1.880	S—
29	2	1.890	S—	2	1.897	S—	1.893	S
30	2	1.959	S	3	1.938	S—	1.948	S—
July 1	2	1.920	U+	2	1.913	S—	1.913	S—
2	2	1.864	U+	3	1.893	S—	1.893	S—
3	2	1.908	S—	....	....	....	1.908	S—
4	2	1.896	S—	....	....	....	1.896	S—
5	3	1.883	S—	....	....	....	1.883	S—
6	....	....	....	....	....	....	....	....
7	....	....	....	....	....	....	....	....
8	3	1.882	S	....	....	....	1.882	S
9	2	1.898	S—	....	....	....	1.898	S—
10	2	1.911	S—	....	....	....	1.911	S—
11	2	1.927	S—	....	....	....	1.927	S—
12	2	1.929	S	3	1.916	S—	1.921	S
13	2	1.936	S	2	1.888	S	1.912	U
14	3	1.912	S	3	1.913	S—	1.912	S
15	2	1.903	S—	2	1.929	S	1.920	S—
16	2	1.907	S—	....	....	....	1.907	S—
17	2	1.906	U	....	....	....	1.906	U
18	2	1.916	S—	....	....	....	1.916	S—
19	....	....	....	....	....	....	....	....
20	1	1.892	U	....	....	....	1.892	U
21	2	1.947	U	....	....	....	1.947	U
22	3	1.929	S—	....	....	....	1.929	S—
23	2	1.925	S—	....	....	....	1.925	S—
24	2	1.926	S—	....	....	....	1.926	S—
25	....	....	....	....	....	....	....	....
26	....	....	....	....	....	....	....	....
27	2	1.918	U	....	....	....	1.918	U
28	1	1.928	U	2	1.907	S—	1.907	S—
29	....	....	....	3	1.927	S—	1.927	S—
30	2	1.903	U	....	....	....	1.903	U
31	....	....	....	....	....	....	....	....

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1922 Aug. 1	....	....	....	2	1.908	S—	1.908	S—
2	....	....	....	....	....	....	....	....
3	3	1.912	S	....	....	....	1.912	S
4	2	1.915	S	....	....	....	1.915	S
5	2	1.889	U	1	1.915	S—	1.915	S—
6	....	....	....	....	....	....	....	....
7	....	....	....	....	....	....	....	....
8	....	....	....	1	1.931	S—	1.931	S—
9	....	....	....	....	....	....	....	....
10	....	....	....	....	....	....	....	....
11	....	....	....	2	1.903	S—	1.903	S—
12	2	1.921	S—	4	1.934	S	1.927	S
13	....	....	....	....	....	....	....	....
14	2	1.945	S	....	....	....	1.945	S
15	2	1.920	U+	....	....	....	1.920	U+
16	1	1.905	U	....	....	....	1.905	U
17	....	....	....	....	....	....	....	....
18	....	....	....	....	....	....	....	....
19	....	....	....	2	1.907	S—	1.907	S—
20	....	....	....	....	....	....	....	....
21	2	1.943	U	....	....	....	....	....
22	....	....	....	....	....	....	....	....
23	....	....	....	....	....	....	....	....
24	....	....	....	....	....	....	....	....
25	3	1.901	S—	....	....	....	1.901	S—
26	2	1.925	S—	1	1.906	S—	1.915	S—
27	2	1.920	S—	2	1.920	S—	1.920	S
28	3	1.931	U	1	1.937	S—	1.934	U
29	2	1.936	U	....	....	....	1.936	U
30	2	1.926	U	3	1.917	S—	1.917	S—
31	2	1.912	U+	....	....	....	1.912	U+
Sept. 1	2	1.937	U+	....	....	....	1.937	U+
2	....	....	....	....	....	....	....	....
3	2	1.890	S—	....	....	....	1.890	S—
4	3	1.939	S—	....	....	....	1.939	S—
5	2	1.928	S—	....	....	....	1.928	S—
6	....	....	....	....	....	....	....	....
7	....	....	....	....	....	....	....	....
8	....	....	....	....	....	....	....	....
9	2·	1.928	S—	....	....	....	1.928	S—
10	3	1.905	S—	....	....	....	1.905	S—
11	2	1.916	S—	....	....	....	1.916	S—
12	4	1.916	S—	....	....	....	1.916	S—
13	....	....	....	....	....	....	....	....
14	3	1.885	S—	....	....	....	1.885	S—
15	2	1.879	S—	1	1.936	U	1.879	S—
16	2	1.871	S—	3	1.927	S—	1.899	S—
17	2	1.857	U?	....	....	....	1.857	U
18	2	1.866	S—	....	....	....	1.866	S—
19	3	1.860	U?	....	....	....	1.860	U?
20	2	1.867	S—	1	1.934	S—	1.900	S—
21	....	....	....	....	....	....	....	....
22	....	....	....	....	....	....	....	....
23	2	1.899	S	....	....	....	1.899	S
24	2	1.894	S—	....	....	....	1.894	S—
25	2	1.916	U	....	....	....	1.916	U
26	2	1.916	S—	....	....	....	1.916	S—
27	2	1.935	U	3	1.919	S	1.919	S
28	2	1.953	U	1	1.976	U	....	....
29	3	1.949	S	3	1.911	S	1.930	S—
30	2	1.914	S	....	....	....	1.914	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1922								
Oct. 1	2	1.918	S—	2	1.924	S	1.922	S
2	1	1.932	U	....	....	....	....	....
3	2	1.910	S—	....	....	....	1.910	S—
4	1	1.923	U	1	1.914	S—	1.914	S—
5	2	1.924	S	3	1.913	S	1.918	S
6	2	1.938	S	3	1.919	S	1.928	S
7	2	1.926	S	3	1.943	S	1.934	S
8	2	1.944	S	2	1.933	S	1.938	S
9	2	1.934	S—	....	....	....	1.934	S—
10	3	1.918	S	3	1.926	S	1.922	S
11	2	1.934	S	3	1.919	S—	1.929	S
12	2	1.936	S	2	1.937	S	1.936	S
13	2	1.932	S	....	....	....	1.932	S
14	2	1.910	S—	....	....	....	1.910	S—
15	2	1.910	S	....	....	....	1.910	S
16	2	1.913	S	....	....	....	1.913	S
17	2	1.913	S	....	....	....	1.913	S
18	2	1.910	S—	....	....	....	1.910	S—
19	2	1.898	S	....	....	....	1.898	S
20	2	1.910	S—	....	....	....	1.910	S—
21	2	1.867	U	....	....	....	....	....
22	3	1.902	S—	....	....	....	1.902	S—
23	2	1.914	S	....	....	....	1.914	S
24	2	1.930	S	....	....	....	1.930	S
25	2	1.934	S	....	....	....	1.934	S
26	....	....	....	....	....	....	....	....
27	2	1.910	S	....	....	....	1.910	S
28	....	....	....	....	....	....	....	....
29	2	1.952	U	1	1.987	U	....	....
30	2	1.893	S	....	....	....	1.893	S
31	2	1.946	U	....	....	....	....	....
Nov. 1	....	....	....	....	....	....	....	....
2	1	1.930	U	....	....	....	....	....
3	2	1.902	S—	3	1.919	S—	1.911	S—
4	2	1.912	S	3	1.945	S—	1.923	S
5	2	1.958	U	....	....	....	....	....
6	2	1.926	S	3	1.908	S—	1.920	S
7	2	1.928	S	....	....	....	1.928	S
8	....	....	....	....	....	....	....	....
9	2	1.928	S	....	....	....	1.928	S
10	2	1.940	U	3	1.941	S	1.941	S
11	2	1.922	S	....	....	....	1.922	S
12	2	1.927	S	....	....	....	1.927	S
13	1	1.899	U	....	....	....	....	....
14	2	1.881	S—	1	1.957	U	....	....
15	2	1.902	U	3	1.923	S—	1.916	S—
16	2	1.916	S	....	....	....	1.916	S
17	2	1.921	S	....	....	....	1.921	S
18	2	1.919	S	....	....	....	1.919	S
19	2	1.920	S	....	....	....	1.920	S
20	2	1.950	S—	1	1.923	S—	1.936	S—
21	2	1.865	U	....	....	....	....	....
22	2	1.858	U	....	....	....	....	....
23	2	1.903	S—	....	....	....	1.903	S—
24	2	1.904	S	....	....	....	1.904	S
25	2	1.915	S	2	1.915	S	1.915	S
26	2	1.924	S	....	....	....	1.924	S
27	....	....	....	....	....	....	....	....
28	2	1.931	S—	....	....	....	1.931	S—
29	....	....	....	....	....	....	....	....
30	....	....	....	2	1.923	S—	1.923	S—

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1922								
Dec. 1	....	....	....	....	....	....	....	....
2	2	1.931	S	2	1.911	S—	1.924	S
3	....	....	....	....	....	....	....	....
4	....	....	....	....	....	....	....	....
5	2	1.920	S	....	....	....	1.920	S
6	2	1.934	U+	....	....	....	1.934	U+
7	....	....	....	....	....	....	....	....
8	2	1.938	S	....	....	....	1.938	S
9	....	....	....	....	....	....	....	....
10	....	....	....	....	....	....	....	....
11	2	1.923	S—	1	1.906	S—	1.914	S—
12	....	....	....	1	1.908	S—	1.908	S—
13	....	....	....	....	....	....	....	....
14	....	....	....	2	1.926	S	1.926	S
15	....	....	....	2	1.920	S	1.920	S
16	1	1.924	S	....	....	....	1.924	S
17	....	....	....	....	....	....	....	....
18	2	1.926	S	....	....	....	1.926	S
19	....	....	....	....	....	....	....	....
20	2	1.924	S	....	....	....	1.924	S
21	2	1.932	S	....	....	....	1.932	S
22	2	1.933	S	....	....	....	1.933	S
23	2	1.927	S	....	....	....	1.927	S
24	2	1.927	S	....	....	....	1.927	S
25	2	1.929	S	1	1.911	U	1.929	S
26	....	....	....	....	....	....	....	....
27	2	1.932	S	....	....	....	1.932	S
28	....	....	....	....	....	....	....	....
29	2	1.944	U	....	....	....	....	....
30	2	1.928	U	....	....	....	....	....
31	....	....	....	....	....	....	....	....
1923								
Jan. 1	2	1.942	S—	....	....	....	·1.942	S—
2	....	....	....	2	1.930	S—	1.930	S–
3	2	1.932	S	....	....	....	1.932	S
4	2	1.942	S	....	....	....	1.942	S
5	....	....	....	....	....	....	....	....
6	....	....	....	....	....	....	....	....
7	1	1.922	S—	....	....	....	1.922	S—
8	2	1.934	S—	....	....	....	1.934	S–
9	2	1.928	S	....	....	....	1.928	S
10	2	1.928	S	....	....	....	1.928	S
11	2	1.924	S	....	....	....	1.924	S
12	2	1.923	S	....	....	....	1.923	S
13	3	1.933	S	....	....	....	1.933	S
14	2	1.916	S—	....	....	....	1.916	S–
15	....	....	....	....	....	....	....	....
16	2	1.933	S	....	....	....	1.933	S
17	....	....	....	....	....	....	....	....
18	2	1.925	U+	....	....	....	1.925	U+
19	....	....	....	....	....	....	....	....
20	2	1.912	S	....	....	....	1.912	S
21	2	1.902	S	....	....	....	1.902	S
22	....	....	....	....	....	....	....	....
23	....	....	....	....	....	....	....	....
24	....	....	....	....	....	....	....	....
25	....	....	....	....	....	....	....	....
26	....	....	....	....	....	....	....	....
27	2	1.930	S	....	....	....	1.930	S
28	2	1.921	S	....	....	....	1.921	S
29	....	....	....	....	....	....	....	....
30	....	....	....	....	....	....	....	....
31	....	....	....	....	....	....	....	....

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1923								
Feb. 1	....	....	....	....	....	....	....	....
2	2	1.919	S—	4	1.915	S	1.916	S
3	1	1.912	S	2	1.915	S	1.914	S
4	2	1.910	S	....	....	....	1.910	S
5	2	1.924	S	3	1.916	S	1.920	S
6	2	1.918	S	....	....	....	1.918	S
7	2	1.907	S	3	1.919	S	1.913	S
8	3	1.920	S	....	....	....	1.920	S
9	....	....	....	....	....	....	....	....
10	3	1.917	S	....	....	....	1.917	S
11	....	....	....	....	....	....	....	....
12	3	1.942	U	....	....	....	1.942	U
13	....	....	....	4	1.933	S	1.933	S
14	....	....	....	....	....	....	....	....
15	3	1.949	S—	....	....	....	1.949	S—
16	3	1.939	S	....	....	....	1.939	S
17	4	1.926	S	....	....	....	1.926	S
18	4	1.913	S	....	....	....	1.913	S
19	....	....	....	....	....	....	....	....
20	....	....	....	....	....	....	....	....
21	....	....	....	....	....	....	....	....
22	3	1.905	U	4	1.917	S	1.917	S
23	2	1.899	U	1	1.909	S	1.909	S
24	....	....	....	2	1.904	S	1.904	S
25	5	1.893	S—	1	1.899	S	1.897	S
26	5	1.890	S—	1	1.905	S	1.900	S
27	4	1.888	S—	1	1.899	S	1.895	S
28	....	....	....	....	....	....	....	....
Mar. 1	....	....	....	....	....	....	....	....
2	....	....	....	....	....	....	....	....
3	....	....	....	....	....	....	....	....
4	....	....	....	2	1.897	S—	1.897	S—
5	5	1.917	S	3	1.910	S	1.913	S
6	3	1.929	S	4	1.904	S—	1.920	S
7	....	....	....	4	1.916	S	1.916	S
8	....	....	....	4	1.909	S	1.909	S
9	3	1.920	S—	4	1.919	S	1.919	S
10	....	....	....	4	1.905	S	1.905	S
11	4	1.902	S	3	1.924	S	1.913	S
12	3	1.939	S—	3	1.918	S	1.925	S
13	1	1.929	U	3	1.923	S	1.923	S
14	1	1.923	U	2	1.924	S—	1.924	S
15	3	1.913	S	4	1.917	S	1.915	S
16	4	1.919	S	....	....	....	1.919	S
17	4	1.862	U	5	1.912	S	1.912	S
18	5	1.901	S—	2	1.913	S	1.909	S
19	5	1.931	U+	4	1.907	S	1.907	S
20	....	....	....	1	1.903	S—	1.903	S—
21	5	1.914	S—	2	1.910	S	1.911	S
22	3	1.931	S—	3	1.895	S—	1.913	S—
23	5	1.918	S	2	1.926	S	1.922	S
24	5	1.912	S	2	1.916	S	1.914	S
25	4	1.917	S	2	1.910	S	1.913	S
26	3	1.920	S	2	1.906	S	1.913	S
27	4	1.908	U	2	1.916	S	1.916	S
28	4	1.888	U	2	1.908	S	1.908	S
29	4	1.869	U	2	1.925	S	1.925	S
30	2	1.860	U	5	1.904	S	1.904	S
31	4	1.875	U	3	1.900	S	1.900	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1923								
Apr. 1	....	....	....	2	1.921	S	1.921	S
2	....	....	....	5	1.921	S	1.921	S
3	3	1.920	S	3	1.911	S	1.915	S
4	....	....	....	5	1.912	S	1.912	S
5	5	1.959	U	5	1.924	S	1.924	S
6	....	....	....	3	1.918	S	1.918	S
7	....	....	....	5	1.916	S	1.916	S
8	3	1.915	S	3	1.892	S	1.904	S
9	5	1.928	S—	2	1.908	U	1.921	S—
10	....	....	....	5	1.913	S	1.913	S
11	....	....	....	5	1.918	S	1.918	S
12	3	1.907	S	5	1.907	S	1.907	S
13	1	1.918	S—	2	1.907	S	1.911	S
14	4	1.913	S—	5	1.908	S	1.910	S
15	5	1.899	S	5	1.906	S	1.903	S
16	5	1.934	U	4	1.906	S	1.906	S
17	....	....	....	2	1.905	S	1.905	S
18	....	....	....	5	1.905	S	1.905	S
19	....	....	....	4	1.912	S	1.912	S
20	3	1.920	S—	....	....	....	1.920	S—
21	4	1.931	U	....	....	....	....	....
22	4	1.920	S—	2	1.910	S	1.913	S
23	3	1.922	S—	5	1.918	S	1.920	S
24	4	1.921	S—	3	1.913	S	1.916	S
25	4	1.931	S—	2	1.918	S	1.922	S
26	2	1.913	S—	5	1.911	S	1.912	S
27	3	1.908	S—	5	1.914	S	1.911	S
28	3	1.919	S	5	1.922	S	1.921	S
29	5	1.911	S	2	1.913	S	1.912	S
30	5	1.921	S—	2	1.904	S	1.910	S
May 1	5	1.930	S	....	....	....	1.930	S
2	3	1.933	U+	5	1.906	S	1.915	S—
3	2	1.931	S	5	1.919	S	1.925	S
4	4	1.927	S—	....	....	....	1.927	S—
5	5	1.933	S—	....	....	....	1.933	S—
6	5	1.902	S	....	....	....	1.902	S
7	3	1.916	S	....	....	....	1.916	S
8	5	1.917	S	....	....	....	1.917	S
9	....	....	....	....	....	....	....	....
10	3	1.905	S	5	1.916	S	1.911	S
11	5	1.933	S—	2	1.918	S	1.923	S
12	....	....	....	4	1.909	S	1.909	S
13	5	1.945	U	2	1.916	S	1.916	S
14	5	1.916	S	....	....	....	1.916	S
15	3.	1.919	S	2	1.886	U	1.919	S
16	4	1.950	U	....	....	....	....	....
17	5	1.919	S	....	....	....	1.919	S
18	5	1.921	S—	2	1.919	S	1.920	S
19	3	1.897	U+	....	....	....	....	....
20	5	1.925	S—	....	....	....	1.925	S—
21	5	1.908	S—	5	1.908	S	1.908	S
22	4	1.924	S	....	....	....	1.924	S
23	5	1.930	S—	....	....	....	1.930	S—
24	3	1.936	U	....	....	....	1.936	U
25	4	1.929	S	....	....	....	1.929	S
26	5	1.926	S	1	1.893	U	1.926	S
27	5	1.920	S	4	1.917	S	1.918	S
28	5	1.929	S—	2	1.911	S	1.917	S
29	4	1.924	U	5	1.908	S—	1.908	S—
30	5	1.940	S—	1	1.927	S—	1.933	S—
31	3	1.922	S—	3	1.930	S	1.927	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1923								
June 1	5	1.925	S	4	1.914	S	1.920	S
2	5	1.920	S—	2	1.902	S	1.911	S
3	4	1.920	S	2	1.897	U	1.920	S
4	5	1.924	S—	2	1.899	S	1.911	S
5	4	1.951	U	5	1.910	S	1.910	S
6	3	1.920	S	....	....	....	1.920	S
7	5	1.908	S	2	1.906	S—	1.907	S
8	5	1.917	S—	4	1.909	S	1.912	S
9	4	1.925	S	4	1.913	S	1.919	S
10	5	1.892	S	1	1.890	U	1.892	S
11	3	1.917	S	4	1.915	S	1.916	S
12	2	1.918	S	2	1.920	S—	1.919	S
13	3	1.921	S	....	....	....	1.921	S
14	4	1.932	U	....	....	....	....	....
15	....	....	....	....	....	....	....	....
16	5	1.901	S—	....	....	....	1.901	S—
17	5	1.925	S—	2	1.917	S	1.920	S
18	5	1.892	U	2	1.922	S—	1.922	S—
19	4	1.929	S	4	1.926	S	1.927	S
20	4	1.896	U	4	1.919	S	1.919	S
21	2	1.982	U	1	1.918	S	1.918	S
22	5	1.927	S	4	1.927	S—	1.927	S
23	5	1.919	S	4	1.914	S	1.916	S
24	5	1.916	S	2	1.913	S	1.914	S
25	4	1.912	U	3	1.928	S	1.928	S
26	3	1.922	U	4	1.925	S	1.925	S
27	5	1.924	S—	4	1.929	S	1.927	S
28	3	1.932	U	4	1.922	S	1.922	S
29	2	1.911	S—	4	1.933	S	1.926	S
30	5	1.934	U	2	1.924	S	1.924	S
July 1	5	1.924	U	2	1.930	S	1.930	S
2	4	1.938	U	2	1.936	S	1.936	S
3	5	1.926	U	2	1.929	S	1.929	S
4	5	1.905	U	2	1.922	S	1.922	S
5	5	1.931	U	2	1.930	S	1.930	S
6	....	....	....	4	1.932	S	1.932	S
7	4	1.956	U	4	1.899	S—	1.899	S—
8	3	1.939	U	2	1.918	S	1.918	S
9	4	1.956	U	....	....	....	....	....
10	....	....	....	2	1.924	S—	1.924	S—
11	....	....	....	2	1.926	S	1.926	S
12	....	....	....	4	1.918	S	1.918	S
13	....	....	....	4	1.914	S	1.914	S
14	....	....	....	2	1.916	S	1.916	S
15	....	....	....	2	1.914	S	1.914	S
16	....	....	....	....	....	....	....	....
17	....	....	....	2	1.927	S	1.927	S
18	....	....	....	....	....	....	....	....
19	....	....	....	....	....	....	....	....
20	....	....	....	2	1.908	S	1.908	S
21	....	....	....	2	1.928	S	1.928	S
22	....	....	....	2	1.937	S	1.937	S
23	....	....	....	2	1.933	S	1.933	S
24	....	....	....	5	1.930	S	1.930	S
25	....	....	....	5	1.937	S	1.937	S
26	....	....	....	2	1.936	S	1.936	S
27	....	....	....	2	1.933	S—	1.933	S—
28	....	....	....	2	1.930	S—	1.930	S—
29	....	....	....	....	....	....	....	....
30	....	....	....	2	1.937	S—	1.937	S—
31	....	....	....	2	1.935	S	1.935	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1923								
Aug. 1	2	1.940	U	....	....	....	1.940	U
2	4	1.922	U	2	1.936	S—	1.936	S—
3	5	1.956	U	2	1.933	S—	1.933	S—
4	3	1.965	U	5	1.928	S	1.928	S
5	4	1.958	U	2	1.933	S	1.933	S
6	4	1.980	U	2	1.934	S	1.934	S
7	5	1.985	U	2	1.929	S	1.929	S
8	4	1.978	U	2	1.933	S	1.933	S
9	....	....	....	2	1.932	S	1.932	S
10	....	....	....	2	1.926	S	1.926	S
11	....	....	....	2	1.923	S—	1.923	S—
12	....	....	....	....	....	....	....	....
13	5	1.957	U	5	1.937	S	1.937	S
14	3	1.960	U	3	1.929	S	1.929	S
15	....	....	....	2	1.932	S	1.932	S
16	....	....	....	2	1.932	S	1.932	S
17	....	....	....	2	1.930	S	1.930	S
18	....	....	....	1	1.937	U+	1.937	U+
19	....	....	....	2	1.913	S	1.913	S
20	4	1.943	U	5	1.937	S	1.937	S
21	3	1.964	U	2	1.932	S	1.932	S
22	5	1.965	U	2	1.924	S	1.924	S
23	....	....	....	2	1.932	S	1.932	S
24	....	....	....	2	1.936	S	1.936	S
25	....	....	....	2	1.928	S	1.928	S
26	....	....	....	2	1.932	S	1.932	S
27	....	....	....	5	1.930	S	1.930	S
28	3	1.917	U	....	....	....	....	....
29	....	....	....	3	1.928	S—	1.928	S—
30	....	....	....	4	1.937	S	1.937	S
31	....	....	....	4	1.934	S	1.934	S
Sept. 1	....	....	....	3	1.940	S	1.940	S
2	....	....	....	3	1.942	S	1.942	S
3	....	....	....	2	1.927	S—	1.927	S—
4	....	....	....	3	1.937	S	1.937	S
5	....	....	....	3	1.939	S	1.939	S
6	4	1.926	U	3	1.937	S	1.937	S
7	5	1.925	U	5	1.933	S	1.933	S
8	....	....	....	3	1.931	S	1.931	S
9	3	1.941	U	2	1.927	S	1.927	S
10	....	....	....	3	1.935	S	1.935	S
11	....	....	....	1	1.938	U+	1.938	U+
12	....	....	....	4	1.940	S	1.940	S
13	5	1.903	U	4	1.938	S	1.938	S
14	....	....	....	4	1.940	S	1.940	S
15	2	1.929	U	5	1.938	S	1.938	S
16	4	1.910	U	1	1.913	U	1.913	U+
17	....	....	....	4	1.921	S	1.921	S
18	4	1.915	U	4	1.933	S	1.933	S
19	5	1.929	S—	4	1.940	S	1.936	S
20	3	1.944	U	5	1.936	S	1.936	S
21	3	1.927	U	5	1.932	S	1.932	S
22	4	1.931	S—	2	1.948	U	1.931	S—
23	....	....	....	4	1.930	S	1.930	S
24	5	1.922	S—	4	1.928	S	1.925	S
25	5	1.917	S	3	1.928	S—	1.921	S
26	5	1.926	S—	....	....	....	1.926	S—
27	5	1.923	S—	4	1.926	S—	1.924	S
28	3	1.938	U	5	1.941	S	1.941	S
29	5	1.927	S—	4	1.938	S	1.934	S
30	....	....	....	4	1.936	S	1.936	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1923								
Oct. 1	....	....	....	4	1.937	S	1.937	S
2	5	1.955	S—	3	1.934	S—	1.941	S—
3	....	....	....	3	1.924	S—	1.924	S—
4	5	1.934	S	2	1.936	S—	1.935	S
5	3	1.948	U	4	1.933	S	1.933	S
6	5	1.921	S	4	1.921	S	1.921	S
7	....	....	....	3	1.909	S	1.909	S
8	3	1.957	U	4	1.941	S	1.941	S
9	5	1.932	S—	4	1.927	S—	1.930	S
10	3	1.955	U	4	1.934	S	1.934	S
11	5	1.929	S	4	1.932	S	1.931	S
12	3	1.921	S	5	1.920	S	1.920	S
13	5	1.929	S	4	1.935	S	1.931	S
14	....	....	....	4	1.938	S	1.938	S
15	5	1.927	S	4	1.935	U+	1.930	S
16	3	1.937	S—	....	....	....	1.937	S—
17	3	1.930	S	4	1.934	S—	1.931	S
18	4	1.940	S	....	....	....	1.940	S
19	....	....	....	4	1.936	S	1.936	S
20	2	1.934	S	5	1.930	S	1.932	S
21	4	1.928	S	4	1.927	S	1.927	S
22	2	1.944	S—	4	1.930	S	1.935	S
23	4	1.939	S	3	1.934	S	1.936	S
24	5	1.910	U	4	1.927	S	1.927	S
25	5	1.933	S—	4	1.929	S	1.930	S
26	3	1.925	S—	1	1.934	U	1.925	S—
27	....	....	....	....	....	....	....	....
28	....	....	....	5	1.928	S	1.928	S
29	3	1.930	U	1	1.922	S—	1.925	S—
30	....	....	....	3	1.929	S—	1.929	S—
31	....	....	....	4	1.926	S	1.926	S
Nov. 1	....	....	....	....	....	....	....	....
2	2	1.932	S	....	....	....	1.932	S
3	4	1.928	S	....	....	....	1.928	S
4	....	....	....	4	1.928	S	1.928	S
5	5	1.910	S	4	1.924	S	1.917	S
6	4	1.925	S	4	1.907	U	1.925	S
7	....	....	....	5	1.924	S	1.924	S
8	2	1.927	U	4	1.919	U	1.923	U+
9	....	....	....	4	1.917	S—	1.917	S—
10	....	....	....	2	1.931	U	1.931	U
11	....	....	....	4	1.920	S	1.920	S
12	5	1.925	S	5	1.929	S	1.927	S
13	2	1.936	S	4	1.939	S	1.938	S
14	2	1.930	S—	4	1.937	S	1.935	S
15	....	....	....	4	1.937	S	1.937	S
16	....	....	....	3	1.938	S	1.938	S
17	....	....	....	4	1.929	S	1.929	S
18	....	....	....	4	1.929	S	1.929	S
19	2	1.954	U	4	1.935	S	1.935	S
20	....	....	....	5	1.945	S	1.945	S
21	....	....	....	4	1.931	S	1.931	S
22	5	1.932	S	2	1.940	U	1.932	S
23	5	1.920	S	3	1.939	S—	1.926	S
24	....	....	....	4	1.938	S—	1.938	S—
25	....	....	....	2	1.950	U	....	....
26	3	1.925	S	4	1.946	U	1.925	S
27	....	....	....	2	1.950	U	....	....
28	....	....	....	3	1.918	U	....	....
29	....	....	....	....	....	....	....	....
30	....	....	....	2	1.926	S—	1.926	S—

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1923								
Dec. 1	....	....	....	....	....	....	....	....
2	....	....	....	1	1.937	U	1.937	U
3	2	1.889	U	....	....	....	....	....
4	4	1.932	S	....	....	....	1.932	S
5	5	1.932	S	....	....	....	1.932	S
6	2	1.940	S	2	1.939	U	1.940	S
7	5	1.933	S—	4	1.932	S	1.932	S
8	4	1.923	S—	....	....	....	1.923	S—
9	....	....	....	....	....	....	....	....
10	....	....	....	5	1.919	S—	1.919	S—
11	....	....	....	4	1.944	U+	1.944	U+
12	5	1.938	S	....	....	....	1.938	S
13	2	1.935	U	3	1.912	U	1.923	U+
14	....	....	....	4	1.922	S	1.922	S
15	5	1.903	S	4	1.940	U+	1.915	S—
16	3	1.917	S	....	....	....	1.917	S
17	5	1.934	S	4	1.913	U	1.934	S
18	....	....	....	4	1.938	S	1.938	S
19	....	....	....	....	....	....	....	....
20	....	....	....	5	1.933	S—	1.933	S—
21	5	1.906	S	....	....	....	1.906	S
22	2	1.900	U	4	1.902	U	1.901	U+
23	5	1.918	S	4	1.903	U	1.913	S—
24	....	....	....	4	1.911	S—	1.911	S—
25	....	....	....	2	1.891	U	1.891	U
26	....	....	....	....	....	....	....	....
27	....	....	....	4	1.915	S	1.915	S
28	....	....	....	4	1.924	S—	1.924	S—
29	....	....	....	5	1.912	S	1.912	S
30	1	1.950	U	....	....	....	....	....
31	5	1.937	S—	4	1.907	S—	1.922	S—
1924								
Jan. 1	3	1.930	S—	4	1.925	S	1.927	S
2	5	1.912	S	5	1.926	S	1.919	S
3	4	1.932	U	5	1.932	S	1.932	S
4	3	1.921	S	4	1.934	S	1.928	S
5	5	1.926	S	....	....	....	1.926	S
6	3	1.928	S	....	....	....	1.928	S
7	5	1.926	S	5	1.928	S	1.927	S
8	5	1.942	S—	5	1.937	S	1.939	S
9	5	1.911	S	....	....	....	1.911	S
10	5	1.931	S	4	1.926	S—	1.929	S
11	3	1.932	S	....	....	....	1.932	S
12	5	1.917	S	3	1.916	U	1.917	S
13	3	1.918	S—	5	1.938	S—	1.928	S
14	1	1.946	U	5	1.935	S	1.935	S
15	5	1.923	S	5	1.939	S	1.931	S
16	3	1.940	U	5	1.926	S	1.926	S
17	5	1.937	U	5	1.921	S	1.921	S
18	5	1.934	S—	5	1.930	S	1.931	S
19	3	1.922	S	5	1.931	S	1.927	S
20	4	1.919	S	5	1.934	S	1.927	S
21	....	....	....	5	1.920	S—	1.920	S—
22	1	1.907	U	5	1.940	S—	1.934	S—
23	5	1.923	S	4	1.925	S—	1.924	S
24	5	1.909	S	....	....	....	1.909	S
25	5	1.921	S	....	....	....	1.921	S
26	5	1.915	S	4	1.934	U+	1.920	S
27	3	1.946	U	5	1.934	S—	1.938	S—
28	5	1.932	U	5	1.939	S	1.939	S
29	3	1.938	U	5	1.929	S—	1.932	S—
30	3	1.931	S	5	1.931	S—	1.931	S
31	5	1.926	S	....	....	....	1.926	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1924 Feb. 1	5	1.919	S	....	....	....	1.919	S
2	5	1.919	S	4	1.926	S—	1.921	S
3	5	1.925	S—	....	....	....	1.925	S
4	5	1.921	S—	2	1.916	S—	1.918	S
5	....	....	....	3	(1.911)	U	1.911	U+
6	1	1.910	U	5	1.904	U+	1.907	U+
7	....	....	....	4	1.912	S—	1.912	S—
8	....	....	....	4	1.934	S	1.934	S
9	5	1.920	S	5	1.929	S	1.925	S
10	5	1.913	S	4	1.936	S—	1.921	S—
11	5	1.868	U	....	....	....	....	....
12	3	1.927	S	3	1.935	S—	1.930	S
13	5	1.921	S	....	....	....	1.921	S
14	3	1.919	U	....	....	....	1.919	U
15	1	1.920	U	....	....	....	1.920	U
16	5	1.912	S	4	(1.888)	U	1.912	S
17	5	1.892	S	....	....	....	1.892	S
18	5	1.911	S	4	(1.898)	S—	1.907	S
19	3	1.917	S	....	....	....	1.917	S
20	3	1.915	S—	....	....	....	1.915	S—
21	5	1.929	S—	....	....	....	1.929	S—
22	5	1.897	U	....	....	....	....	....
23	5	1.944	U	5	1.928	S	1.928	S
24	5	1.917	S	....	....	....	1.917	S
25	5	1.924	S	5	1.931	S	1.927	S
26	5	1.921	S	5	1.924	S	1.923	S
27	3	1.925	U	5	1.918	S	1.918	S
28	5	1.924	S	5	1.922	S	1.923	S
29	5	1.927	S	5	1.924	S	1.925	S
Mar. 1	1	1.934	U	5	1.936	S	1.936	S
2	5	1.910	S—	5	1.938	S	1.929	S
3	1	1.952	U	5	1.937	S	1.937	S
4	2	1.872	U	5	1.936	S	1.936	S
5	5	1.908	U	5	1.927	S	1.927	S
6	5	1.917	S	5	1.925	S	1.921	S
7	5	1.900	S	5	1.927	S—	1.914	S
8	5	1.906	S	1	1.918	S—	1.910	S
9	5	1.919	S	5	1.932	S	1.925	S
10	4	1.938	S	5	1.932	S	1.935	S
11	5	1.921	S—	5	1.908	S—	1.914	S—
12	1	1.875	U	2	1.923	S—	1.923	S—
13	5	1.924	S	4	1.931	S—	1.926	S
14	2	1.936	U	5	1.913	S	1.913	S
15	5	1.916	S	1	1.919	U	1.916	S
16	5	1.895	S	5	1.887	U	1.895	S
17	4	1.935	U	2	(1.877)	U	1.906	U
18	....	....	....	5	1.917	S—	1.917	S—
19	3	1.886	S—	5	1.932	S	1.917	S—
20	5	1.920	U	5	1.915	S	1.915	S
21	....	....	....	4	1.917	S	1.917	S
22	5	1.897	S	5	1.920	S	1.909	S
23	5	1.916	S	4	1.920	S	1.918	S
24	4	1.933	S	5	1.924	S	1.928	S
25	....	....	....	....	....	....	....	....
26	3	1.938	S	5	1.905	S—	1.929	S
27	1	1.923	U	....	....	....	1.923	U
28	....	....	....	3	1.884	U	1.884	U
29	5	1.898	S—	5	1.891	S—	1.895	S
30	5	1.880	U	5	1.921	S	1.907	S—
31	5	1.901	S	5	1.917	S	1.909	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1924								
Apr. 1	4	1.893	S	5	1.921	S	1.907	S
2	3	1.926	U	5	1.915	S	1.915	S
3	2	1.882	U	....	....	....	....	....
4	5	1.930	U	2	1.924	U	1.927	U+
5	5	1.932	S—	....	....	....	1.932	S—
6	....	....	....	5	1.917	S	1.917	S
7	5	1.922	U	....	....	....	1.922	U+
8	....	....	....	....	....	....	....	....
9	5	1.898	S—	4	1.908	S—	1.903	S—
10	1	1.896	U	5	1.920	S—	1.916	S—
11	....	....	....	5	1.914	S	1.914	S
12	3	1.908	S	3	1.911	S—	1.909	S
13	4	1.914	U	5	1.924	S	1.921	S
14	5	1.906	S	5	1.915	S	1.910	S
15	3	1.915	U	5	1.909	S	1.909	S
16	5	1.902	S	4	1.913	U+	1.906	S
17	5	1.910	S	5	1.918	S	1.914	S
18	5	1.915	S	5	1.923	S	1.919	S
19	5	1.915	S	....	....	....	1.915	S
20	5	1.912	S—	2	1.904	U	1.909	S
21	5	1.897	S	5	1.920	S	1.908	S
22	5	1.919	S—	5	1.913	S	1.915	S
23	4	1.928	U	5	1.927	S	1.927	S
24	....	....	....	5	1.918	S	1.918	S
25	....	....	....	4	1.914	S—	1.914	S—
26	5	1.925	S	5	1.923	S	1.924	S
27	1	1.932	U	5	1.921	S	1.921	S
28	4	1.924	U	5	1.921	S	1.921	S
29	4	1.922	S	3	1.917	S—	1.920	S
30	5	1.915	S	4	1.908	S	1.911	S
May 1	2	1.921	S—	....	....	....	1.921	S—
2	3	1.862	U	....	....	....	....	....
3	5	1.887	S—	5	1.926	S	1.913	S—
4	....	....	....	5	1.922	S	1.922	S
5	5	1.925	S	5	1.918	S	1.921	S
6	5	1.927	S	5	1.922	S	1.924	S
7	9	1.926	S	4	1.912	S	1.919	S
8	4	1.928	S	5	1.917	S	1.922	S
9	5	1.922	S	5	1.922	S	1.922	S
10	3	1.931	U	5	1.896	U	1.914	U
11	5	1.931	S—	5	1.920	S—	1.925	S
12	4	1.929	S	5	1.921	S—	1.926	S
13	5	1.944	S—	5	1.921	S	1.929	S
14	5	1.921	S	1	1.920	U	1.921	S
15	5	1.919	S	5	1.913	S	1.916	S
16	5	1.908	S	5	1.929	S	1.919	S
17	5	1.895	S—	3	1.932	U	1.907	S—
18	5	1.860	U	2	1.921	U	....	....
19	5	1.921	U	4	1.924	S	1.924	S
20	5	1.916	S	4	1.919	S	1.918	S
21	5	1.922	S	4	1.923	S	1.922	S
22	3	1.922	S	5	1.929	S	1.926	S
23	5	1.930	S	1	1.943	U	1.930	S
24	5	1.920	S	5	1.923	S—	1.921	S
25	5	1.907	S—	5	1.926	S	1.920	S
26	5	1.915	S	5	1.929	S	1.922	S
27	5	1.917	S	5	1.926	S	1.922	S
28	5	1.850	U	5	1.927	S	1.927	S
29	5	1.888	U	5	1.928	S	1.928	S
30	....	....	....	4	1.928	S	1.928	S
31	5	1.915	S—	5	1.924	S	1.921	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1924								
June 1	5	1.893	S—	4	1.929	S	1.917	S
2	5	1.838	U	5	1.926	S	1.926	S
3	5	1.847	U	5	1.934	S	1.934	S
4	5	1.898	U	3	1.927	S—	1.927	S—
5	5	1.873	U	....	....	....	....	....
6	5	1.899	S	3	1.928	U+	1.909	S—
7	5	1.908	U	3	1.924	U	1.916	U+
8	2	1.880	U	....	....	....	....	....
9	5	1.915	S	4	1.929	S	1.922	S
10	5	1.918	S—	4	1.943	U+	1.925	S—
11	5	1.906	S—	2	1.937	U	1.916	U+
12	3	1.915	S—	4	1.931	S—	1.923	S—
13	5	1.914	U	5	1.926	S	1.926	S
14	3	1.914	S	....	....	....	1.914	S
15	3	1.905	S	....	....	....	1.905	S
16	5	1.911	S	5	1.922	S—	1.915	S
17	5	1.935	S	5	1.931	S—	1.934	S
18	5	1.927	S	2	1.931	S—	1.928	S
19	3	1.917	S	4	1.926	S—	1.920	S
20	3	1.931	S	....	....	....	1.931	S
21	3	1.928	S	....	....	....	1.928	S
22	5	1.911	S	5	1.925	S	1.918	S
23	3	1.907	S—	5	1.922	S	1.917	S
24	6	1.932	S	5	1.933	S—	1.932	S
25	2	1.924	S	....	....	....	1.924	S
26	5	1.918	S—	4	1.919	S	1.919	S
27	3	1.931	S—	2	1.931	U	1.931	S
28	....	....	....	5	1.925	S	1.925	S
29	....	....	....	5	1.926	S	1.926	S
30	....	....	....	5	1.934	S	1.934	S
July 1	....	....	....	5	1.929	S	1.929	S
2	....	....	....	4	1.930	S	1.930	S
3	....	....	....	3	1.926	U	1.926	U
4	....	....	....	....	....	....	....	....
5	....	....	....	4	1.917	S—	1.917	S—
6	....	....	....	5	1.916	S	1.916	S
7	....	....	....	5	1.918	S	1.918	S
8	....	....	....	5	1.925	S	1.925	S
9	....	....	....	5	1.920	S	1.920	S
10	3	1.916	S—	5	1.922	S	1.920	S
11	3	1.927	S—	5	1.921	S	1.923	S
12	3	1.930	U	5	1.912	S—	1.918	S—
13	....	....	....	4	1.927	S—	1.927	S—
14	5	1.942	U	5	1.922	S	1.922	S
15	....	....	....	5	1.937	S	1.937	S
16	5	1.925	S	5	1.927	S	1.926	S
17	3	1.915	S	5	1.920	S	1.918	S
18	2	1.917	S	4	1.925	S	1.921	S
19	2	1.925	S	5	1.926	S	1.926	S
20	3	1.922	S	4	1.924	S	1.923	S
21	3	1.927	S	5	1.920	S	1.923	S
22	4	1.924	U+	4	1.937	S	1.932	S
23	....	....	....	5	1.924	S	1.924	S
24	....	....	....	5	1.914	S	1.914	S
25	....	....	....	5	1.908	S—	1.908	S—
26	....	....	....	4	1.918	S—	1.918	S—
27	....	....	....	5	1.920	S	1.920	S
28	5	1.929	S—	5	1.923	S	1.925	S
29	3	1.937	U	....	....	....	....	....
30	....	....	....	4	1.910	S	1.910	S
31	....	....	....	....	....	....	....	....

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1924								
Aug. 1	....	....	....	5	1.871	U	....	....
2	....	....	....	2	1.909	U	....	....
3	....	....	....	5	1.928	S	1.928	S
4	....	....	....	5	1.935	S—	1.935	S—
5	....	....	....	5	1.927	S—	1.927	S—
6	....	....	....	I	1.914	U	....	....
7	....	....	....	....	....	....	....	....
8	....	....	....	....	....	....	....	....
9	....	....	....	5	1.927	S	1.927	S
10	....	....	....	5	1.911	S	1.911	S
11	....	....	....	4	1.907	U	....	....
12	....	....	....	....	....	....	....	....
13	....	....	....	4	1.915	S—	1.915	S—
14	....	....	....	5	1.914	S	1.914	S
15	....	....	....	5	1.911	S	1.911	S
16	....	....	....	5	1.922	S	1.922	S
17	....	....	....	5	1.920	S	1.920	S
18	....	....	....	5	1.913	S	1.913	S
19	....	....	....	5	1.910	S	1.910	S
20	3	1.939	S	5	1.844	U	1.939	S—
21	5	1.912	S	....	....	....	1.912	S
22	4	1.968	U	....	....	....	....	....
23	....	....	....	....	....	....	....	....
24	....	....	....	5	1.907	S	1.907	S
25	4	1.942	U	5	1.908	S	1.908	S
26	5	1.930	S	5	1.928	S	1.929	S
27	2	1.922	S	5	1.922	S	1.922	S
28	....	....	....	5	1.918	S	1.918	S
29	....	....	....	....	....	....	....	....
30	....	....	....	5	1.914	U	....	....
31	....	....	....	3	1.910	S—	1.910	S—
Sept. 1	....	....	....	3	1.919	S—	1.919	S—
2	....	....	....	5	1.914	S—	1.914	S—
3	....	....	....	4	1.910	S—	1.910	S—
4	....	....	....	5	1.887	S—	1.887	S—
5	....	....	....	5	1.921	U	1.921	U
6	....	....	....	5	1.928	S—	1.928	S—
7	....	....	....	5	1.919	S	1.919	S
8	....	....	....	3	1.922	S—	1.922	S—
9	....	....	....	2	1.920	U	1.920	U
10	....	....	....	....	....	....	....	....
11	3	1.908	S	4	1.928	S	1.918	S
12	4	1.904	S	5	1.913	S	1.909	S
13	5	1.902	S—	5	1.927	S	1.919	S
14	5	1.937	S	5	1.926	S	1.931	S
15	....	....	....	5	1.919	S	1.919	S
16	5	1.023	S	....	....	....	1.923	S
17	5	1.886	U	5	1.919	S	1.919	S
18	5	1.887	U	....	....	....	....	....
19	3	1.902	S—	3	1.926	S—	1.914	S—
20	....	....	....	5	1.926	S	1.926	S
21	3	1.936	S—	5	1.924	S	1.928	S
22	5	1.938	U	5	1.925	S—	1.925	S—
23	5	1.966	U	5	1.907	S—	1.907	S—
24	3	1.938	S	5	1.892	U	....	....
25	4	1.940	S—	4	1.906	S	1.917	S—
26	5	1.927	S	5	1.932	S	1.930	S
27	5	1.936	S	5	1.922	S	1.929	S
28	5	1.932	U	5	1.917	S	1.922	S
29	5	1.926	S—	....	....	....	1.926	S—
30	5	1.941	U	5	1.934	S	1.934	S

TABLE I.—*Daily Solar-Constant Values* (Continued)

Date	Harqua Hala			Montezuma			General mean	
	Number observations	Weighted mean	Grade	Number observations	Weighted mean	Grade	Solar constant	Grade
1924								
Oct. 1	5	1.884	U+	....	....	....	....	....
2	5	1.933	U+	....	....	....	1.933	U+
3	2	1.927	S	....	....	....	1.927	S
4	5	1.911	S—	3	1.928	S—	1.920	S—
5	5	1.942	S—	4	1.938	S—	1.940	S—
6	....	....	....	5	1.932	S	1.932	S
7	5	1.916	U	5	1.930	S	1.930	S
8	3	1.922	S	5	1.926	S—	1.923	S
9	....	....	....	5	1.929	S	1.929	S
10	5	1.935	U	5	1.942	U	1.939	U+
11	5	1.936	S	5	1.930	S—	1.934	S
12	5	1.937	S	5	1.926	S	1.931	S
13	5	1.951	U+	4	1.927	S—	1.927	S—
14	5	1.941	S—	4	1.921	S	1.931	S
15	3	1.936	S	5	1.925	S	1.930	S
16	5	1.938	U	1	1.940	U	1.939	U+
17	5	1.936	S	5	1.923	S	1.929	S
18	5	1.939	S	5	1.928	S	1.933	S
19	5	1.934	S	5	1.924	S	1.929	S
20	5	1.937	S	5	1.926	S	1.931	S
21	3	1.939	S	5	1.927	S—	1.935	S
22	5	1.941	S	5	1.931	S—	1.938	S
23	5	1.926	S	5	1.934	S	1.930	S
24	5	1.920	S—	5	1.934	S	1.929	S
25	5	1.899	S—	5	1.922	S	1.915	S
26	5	1.925	U	5	1.931	S	1.931	S
27	5	1.934	S	5	1.944	U	1.934	S
28	5	1.945	S—	5	1.918	S	1.927	S
29	....	....	....	5	1.928	S	1.928	S
30	4	1.958	U+	5	1.921	S	1.933	S
31	3	1.949	S—	5	1.931	S	1.937	S
Nov. 1	....	....	....	5	1.901	S—	1.901	S—
2	5	1.916	S	5	1.942	S—	1.925	S
3	5	1.912	S	5	1.942	S—	1.922	S
4	5	1.922	S	5	1.922	S—	1.922	S
5	2	1.941	U	5	1.933	S	1.933	S
6	5	1.948	S	5	1.925	S	1.936	S
7	3	1.936	S	5	1.929	S	1.932	S
8	4	1.943	U	5	1.927	S	1.927	S
9	5	1.931	S	5	1.933	S	1.932	S
10	....	....	....	5	1.943	S	1.943	S
11	5	1.955	S—	5	1.935	S	1.942	S
12	5	1.938	S	4	1.933	S	1.935	S
13	1	1.969	U	4	1.931	S	1.931	S
14	5	1.932	S	5	1.927	S	1.930	S
15	....	....	....	5	1.932	S	1.932	S
16	5	1.927	S	4	1.933	S—	1.930	S
17	5	1.933	S	....	....	....	1.933	S
18	3.	1.943	S	4	1.930	S—	1.939	S
19	5	1.943	S	5	1.931	S	1.937	S
20	....	....	....	5	1.938	S	1.938	S
21	5	1.940	S	3	1.928	S—	1.936	S
22	....	....	....	5	1.921	S—	1.921	S—
23	5	1.943	S	....	....	....	1.943	S
24	3	1.932	S	4	1.936	S—	1.933	S
25	5	1.931	U	....	....	....	1.931	U
26	....	....	....	....	....	....	....	....
27	....	....	....	5	1.917	S	1.917	S
28	....	....	....	4	1.932	S—	1.932	S—
29	....	....	....	5	1.927	S	1.927	S
30	....	....	....	5	1.933	S—	1.933	S—

Table 2 contains certain corrections applicable to table 42, pages 149, 150, of Volume IV of the Annals of the Astrophysical Observatory. These modifications result from computations made by the " short method " with data received from Calama after Volume IV went to press.

TABLE 2.—*Corrected Solar-Constant Values,*
Calama, Chile, 1918

[Vol. IV, Annals of the Astrophysical Observatory, page 149]

Date	Former value	Corrected value
Oct. 13	1.901	1.951
25	1.895	1.882
Nov. 19	1.940	1.931
20	1.975	1.963
25	2.002	1.990
26	1.936	1.924
Dec. 8	1.937	1.925
9	1.949	1.939
10	1.949	1.947
22	1.937	1.925
23	1.990	1.984
26	1.961	1.952

In table 3 we give the decade mean values corresponding to column 8 of table 1. We give these values as far back as the year 1918 when daily observations were begun. These results are plotted in figure 1 (p. 34). To fix ideas, we have drawn a heavy line at 1.938 calories. This value is the mean of 78 monthly mean values published in table 53 of Vol. IV of the Annals of the Astrophysical Observatory. From the march of these data, the reader may perceive that a very pronounced depression of solar-constant values has occurred since March, 1922, but that we may be now returning towards a condition of higher ones. This state of affairs is not, indeed, surprising, because we have recently passed through the minimum of sun-spots, and are now to expect greater solar activity. See figure 2 (p. 38).

In order to give a concrete impression of the closeness of correspondence between the two stations, we have taken by months the means of the daily differences between the weighted mean values for Harqua Hala and Montezuma. These results appear in table 4. We give also the differences of monthly mean values, with and without regard to signs, for each individual month in table 5. At the end of table 5, we add the means of the same for all years combined. The reader will note that these general mean differences show but little tendency to indicate a separation between the stations of yearly or half

TABLE 3.—*Decade and Monthly Mean Solar-Constant Values, 1918 to 1924*

Decade	1918 Calama	No.	1919 Calama	No.	Harqua Hala	No.	1920 Calama	No.	Gen. mean	No.	1921 Harqua Hala	No.	Montezuma	No.	Gen. mean	No.
Jan. 1...	.....	..	1.943	5	.....	..	1.968	6	.....	..	1.993	3	1.956	6	1.964	7
2...	.....	..	1.948	8	.....	..	1.967	8	.....	..	1.961	5	1.953	3	1.956	6
3...	.....	..	1.938	6	.....	..	1.959	11	.....	..	1.950	5	.....	..	1.950	5
Mean ...	.....	..	1.943	19	.....	..	1.964	25	.....	..	1.964	13	1.955	9	1.957	18
Feb. 1...	.....	..	1.962	6	.....	..	1.958	5	.....	..	1.942	5	.....	..	1.942	5
2...	.....	..	1.951	9	.....	..	1.954	9	.....	..	1.954	9	1.952	2	1.954	8
3...	.....	..	1.930	5	.....	..	1.956	5	.....	..	1.946	4	1.958	5	1.954	7
Mean ...	.....	..	1.949	20	.....	..	1.956	19	.....	..	1.949	18	1.956	7	1.951	20
Mar. 1...	.....	..	1.950	6	.....	..	1.959	8	.....	..	1.956	2	1.954	8	1.954	8
2...	.....	..	1.942	4	.....	..	1.948	10	.....	..	1.936	2	1.940	4	1.939	5
3...	.....	..	1.931	6	.....	..	1.932	10	.....	..	1.942	5	.....	..	1.942	5
Mean ...	.....	..	1.941	16	.....	..	1.945	28	.....	..	1.944	9	1.949	12	1.946	18
Apr. 1...	.....	..	1.943	10	.....	..	1.948	10	.....	..	1.940	3	1.951	7	1.949	8
2...	.....	..	1.957	8	.....	..	1.956	10	.....	..	1.950	4	1.941	7	1.945	8
3...	.....	..	1.961	8	.....	..	1.952	10	.....	..	1.950	8	1.934	2	1.946	10
Mean ...	.....	..	1.953	26	.....	..	1.952	30	.....	..	1.948	15	1.944	16	1.947	26
May 1...	.....	..	1.953	10	.....	..	1.950	10	.....	..	1.954	4	1.946	6	1.950	9
2...	.....	..	1.921	9	.....	..	1.961	8	.....	..	1.950	6	1.939	2	1.949	7
3...	.....	..	1.945	8	.....	..	1.950	11	.....	..	1.959	5	1.941	4	1.950	7
Mean ...	.....	..	1.940	27	.....	..	1.953	29	.....	..	1.954	15	1.943	12	1.950	23
June 1...	.....	..	1.957	7	.....	..	1.943	10	.....	..	1.930	6	1.933	4	1.927	6
2...	.....	..	1.938	5	.....	..	1.934	7	.....	..	1.943	6	1.936	5	1.939	7
3...	.....	..	1.962	10	.....	..	1.938	6	.....	..	1.933	10	1.945	8	1.936	10
Mean ...	.....	..	1.955	22	.....	..	1.939	23	.....	..	1.935	22	1.939	17	1.934	23
July 1...	.....	..	1.951	7	.....	..	1.945	10	.....	..	1.936	5	1.951	5	1.941	9
2...	.....	..	1.961	9	.....	..	1.940	6	.....	..	1.945	3	1.948	4	1.947	7
3...	1.921	5	1.950	11	.....	..	1.951	5	.....	..	1.937	3	1.944	8	1.946	9
Mean ...	1.921	5	1.954	27	.....	..	1.945	21	.....	..	1.939	11	1.947	17	1.945	25
Aug. 1...	1.955	8	1.961	10	.....	[1]	1.930	8	.....	..	1.934	4	1.935	1	1.934	4
2...	1.945	8	1.942	9	.....	..	1.927	9	.....	..	1.947	5	.....	..	1.947	5
3...	1.959	11	1.955	11	.....	..	1.932	10	.....	..	1.927	3	.....	..	1.927	3
Mean ...	1.954	27	1.953	30	.....	..	1.930	27	.....	..	1.937	12	1.935	1	1.937	12
Sept. 1...	1.942	5	1.938	10	.....	..	1.951	9	.....	..	1.940	10	.....	..	1.940	10
2...	1.946	6	1.942	9	.....	..	1.944	9	.....	..	1.947	10	.....	..	1.947	10
3...	1.944	7	1.937	9	.....	..	1.944	7	.....	..	1.940	6	1.953	5	1.946	8
Mean ...	1.944	18	1.939	28	.....	..	1.947	25	.....	..	1.943	26	1.953	5	1.944	28
Oct. 1...	1.951	10	1.947	4	1.947	2	1.942	9	1.942	9	1.941	7	1.943	7	1.943	8
2...	1.930	8	1.949	8	1.956	4	1.950	6	1.951	7	1.940	8	1.953	2	1.942	9
3...	1.933	6	1.960	7	1.931	5	1.943	7	1.938	10	1.951	8	1.950	2	1.951	10
Mean ...	1.939	24	1.953	19	1.943	11	1.944	22	1.944	26	1.944	23	1.946	11	1.945	27
Nov. 1...	1.928	6	1.958	9	1.956	5	1.951	10	1.952	10	1.954	7	1.952	1	1.954	7
2...	1.945	8	1.951	6	1.952	5	1.946	8	1.948	8	1.957	7	1.948	5	1.955	9
3...	1.947	9	1.948	10	1.926	1	1.945	7	1.943	7	1.966	4	1.951	8	1.954	9
Mean ...	1.941	23	1.953	25	1.952	11	1.948	25	1.948	25	1.958	18	1.950	14	1.954	25
Dec. 1...	1.962	10	1.944	8	.....	..	1.957	7	1.957	7	1.946	6	1.955	10	1.952	10
2...	1.969	3	1.949	7	1.957	1	1.957	10	1.957	10	1.954	3	1.936	2	1.948	4
3...	1.960	6	1.958	8	1.946	3	1.956	4	1.949	5	1.948	2	.....	..	1.948	2
Mean ...	1.962	19	1.950	23	1.948	4	1.957	21	1.955	22	1.948	11	1.952	12	1.950	16

[1] This and subsequent values from Montezuma.

(32)

Decade		Harqua Hala	No.	Montezuma	No.	Gen. mean	No.	Harqua Hala	No.	Montezuma	No.	Gen. mean	No.	Harqua Hala	No.	Montezuma	No.	Gen. mean	No.
				1922						1923						1924			
Jan.	1	1.938	4	1.923	1	1.934	5	1.933	7	1.930	1	1.932	8	1.925	9	1.930	7	1.928	10
	2	1.944	6	1.945	9	1.945	10	1.924	7	.....	..	1.924	7	1.924	7	1.932	8	1.927	10
	3	1.940	5	1.951	9	1.950	9	1.918	3	.....	..	1.918	3	1.924	9	1.932	8	1.927	11
Mean	.	1.941	15	1.947	19	1.945	24	1.926	17	1.930	1	1.926	18	1.924	26	1.931	23	1.927	31
Feb.	1	1.944	4	1.910	1	1.937	5.	1.916	8	1.916	4	1.916	8	1.918	7	1.921	8	1.919	10
	2	1.949	7	1.946	3	1.948	9	1.934	5	1.933	1	1.934	6	1.915	9	1.916	2	1.915	9
	3	.....	..	1.947	5	1.947	5	1.890	3	1.905	6	1.904	6	1.924	6	1.924	6	1.924	8
Mean	.	1.947	11	1.942	9	1.945	19	1.917	16	1.912	11	1.918	20	1.918	22	1.922	16	1.919	27
Mar.	1	1.933	5	1.948	2	1.938	7	1.922	3	1.909	7	1.911	7	1.918	5	1.931	10	1.927	10
	2	1.934	4	1.938	4	1.937	7	1.915	5	1.916	9	1.915	10	1.913	6	1.914	8	1.914	10
	3	1.923	4	1.931	5	1.929	7	1.919	6	1.911	11	1.912	11	1.911	8	1.911	9	1.912	10
Mean	.	1.930	13	1.937	11	1.934	21	1.918	14	1.912	27	1.913	28	1.913	19	1.919	27	1.918	30
Apr.	1	1.931	5	1.929	5	1.930	9	1.921	3	1.914	10	1.916	10	1.912	6	1.918	6	1.917	8
	2	1.920	8	1.936	3	1.925	9	1.911	5	1.908	9	1.911	10	1.910	8	1.914	9	1.913	10
	3	1.924	4	1.924	3	1.923	6	1.918	9	1.914	9	1.916	9	1.916	5	1.918	10	1.918	10
Mean	.	1.924	17	1.930	11	1.927	24	1.917	17	1.912	28	1.914	29	1.912	19	1.917	25	1.916	28
May	1	1.923	6	1.923	2	1.920	8	1.922	9	1.914	3	1.920	9	1.921	8	1.918	8	1.920	9
	2	1.934	10	1.924	3	1.932	10	1.917	7	1.915	4	1.916	9	1.920	8	1.922	8	1.921	9
	3	1.924	9	.....	..	1.924	9	1.926	10	1.917	6	1.923	11	1.918	8	1.926	10	1.924	11
Mean	.	1.928	25	1.924	5	1.926	27	1.923	26	1.916	13	1.920	29	1.920	24	1.922	26	1.922	27
June	1	1.937	10	1.909	3	1.934	10	1.917	9	1.908	7	1.912	10	1.907	5	1.930	8	1.922	8
	2	1.915	9	1.912	4	1.914	9	1.918	6	1.924	6	1.918	8	1.918	9	1.929	7	1.921	10
	3	1.900	6	1.919	3	1.902	7	1.919	5	1.923	10	1.923	10	1.922	7	1.927	8	1.925	10
Mean	.	1.920	25	1.913	10	1.919	26	1.918	20	1.918	23	1.918	28	1.916	21	1.929	23	1.923	28
July	1	1.896	6	1.903	2	1.898	8	.....	..	1.924	9	1.924	9	1.916	1	1.922	9	1.922	9
	2	1.914	9	1.912	4	1.913	9	.....	..	1.918	7	1.918	7	1.923	7	1.924	10	1.924	10
	3	1.925	6	1.917	2	1.923	8	.....	..	1.934	10	1.934	10	1.927	3	1.919	9	1.919	9
Mean	.	1.912	21	1.911	8	1.911	25	.....	..	1.926	26	1.926	26	1.923	11	1.922	28	1.922	28
Aug.	1	1.914	2	1.918	3	1.916	5	.....	..	1.932	9	1.932	9	.....	..	1.926	5	1.926	5
	2	1.923	4	1.915	3	1.918	6	.....	..	1.930	9	1.930	9	1.939	1	1.915	7	1.918	8
	3	1.921	6	1.920	4	1.919	7	.....	..	1.931	10	1.931	10	1.921	3	1.916	6	1.915	7
Mean	.	1.920	12	1.918	10	1.918	18	.....	..	1.931	28	1.931	28	1.926	4	1.918	18	1.919	20
Sept.	1	1.921	6	.....	..	1.921	6	.....	..	1.935	10	1.935	10	.....	..	1.916	9	1.916	9
	2	1.880	9	1.930	2	1.886	9	1.929	1	1.934	10	1.933	10	1.913	6	1.923	8	1.920	9
	3	1.922	8	1.915	2	1.913	7	1.924	6	1.932	8	1.930	10	1.933	6	1.921	8	1.924	9
Mean	.	1.905	23	1.922	4	1.907	22	1.925	7	1.934	28	1.933	30	1.923	12	1.920	25	1.920	27
Oct.	1	1.927	8	1.925	7	1.924	9	1.936	4	1.930	10	1.930	10	1.928	6	1.932	7	1.930	9
	2	1.917	10	1.928	2	1.916	10	1.931	8	1.932	8	1.933	10	1.937	9	1.927	10	1.931	10
	3	1.914	6	.....	..	1.914	6	1.933	6	1.928	9	1.929	10	1.935	9	1.928	1	1.931	11
Mean	.	1.919	24	1.926	9	1.919	24	1.933	18	1.930	27	1.931	30	1.934	24	1.929	27	1.931	30
Nov.	1	1.927	8	1.928	4	1.925	6	1.924	5	1.924	6	1.925	9	1.928	6	1.930	10	1.927	10
	2	1.916	10	1.934	3	1.922	8	1.930	3	1.934	10	1.933	10	1.939	7	1.932	9	1.935	10
	3	1.900	7	1.918	2	1.917	6	1.926	3	1.934	4	1.930	6	1.936	4	1.928	7	1.932	8
Mean	.	1.915	25	1.928	9	1.921	20	1.926	11	1.931	20	1.929	25	1.934	17	1.930	26	1.931	28
Dec.	1	1.931	4	1.911	1	1.927	3	1.932	5	1.932	4	1.931	7	.....	..	.....	..	.....	..
	2	1.924	4	1.915	4	1.920	7	1.925	5	1.932	6	1.929	9	.....	..	.....	..	.....	..
	3	1.932	8	1.911	1	1.930	6	1.915	4	1.911	7	1.911	9	.....	..	.....	..	.....	..
Mean	.	1.930	16	1.914	6	1.925	16	1.925	14	1.923	17	1.923	25	.....	..	.....	..	.....	..

Fig. 1.
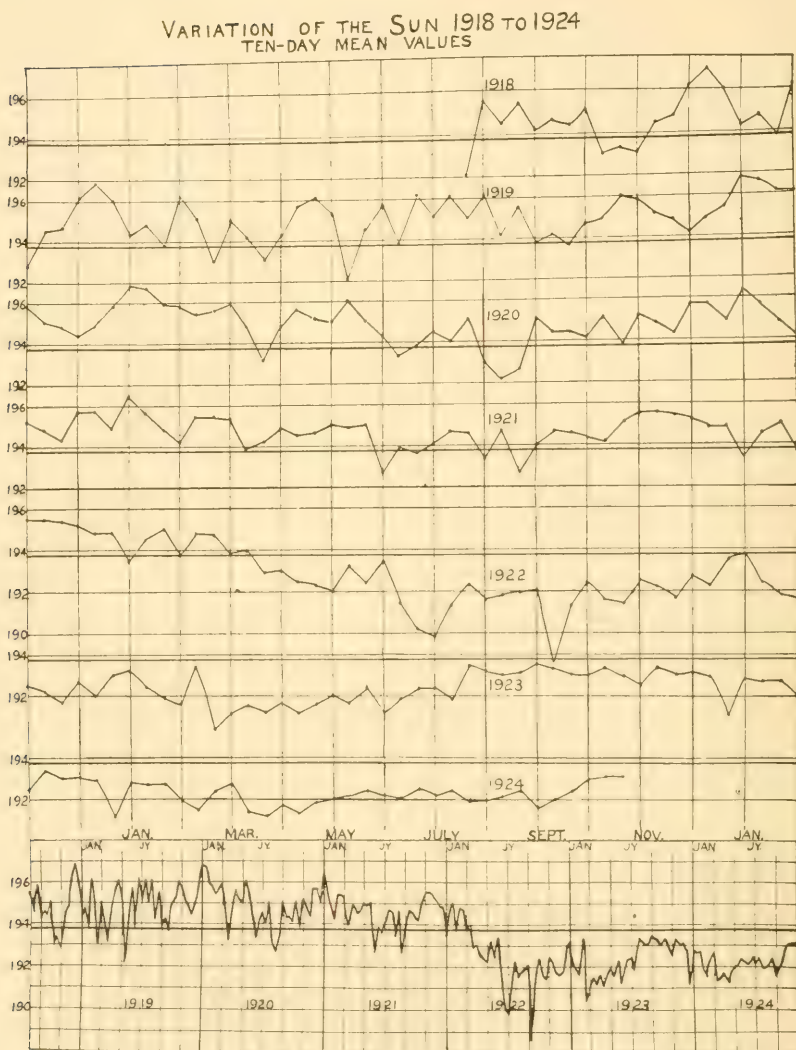
TABLE 4.—*Mean of Daily Differences, Harqua Hala—Montezuma* [1]
All Days Graded "Unsatisfactory" Omitted

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1920													
No. of days	3	....	....	....	....	....	....	....	....	6	9	3	18
Mean regarding signs	+37									+2	+1	0	+1
Mean disregarding signs	±37									±12	±17	±7	±12
1921													
No. of days		4	2	6	4	11	2	1	3	6	7	7	56
Mean regarding signs		+7	−24	−2	−7	−2	−5	+3	−16	+3	+4	−11	0
Mean disregarding signs		±13	±24	±11	±11	±14	±5	±3	±19	±12	±12	±14	±15
1922													
No. of days	9	1	2	4	2	9	3	2	1*	8	4	2	46
Mean regarding signs	0	+15	−2	−2	−4	+11	−5	−3	−38	+3	−4	−18	+4
Mean disregarding signs	±12	±15	±4	±20	±5	±13	±13	±10	±38	±11	±21	±18	±13
1923													
No. of days	....	7	13	14	8	14	....	....	5	12	5	2	80
Mean regarding signs		−5	+5	+6	+6	+4			−8	+3	−9	−16	+1
Mean disregarding signs		±8	±13	±9	±10	±8			±8	±6	±9	±16	±10
1924													
No. of days	12	10	15	11	18	12	9	1	8	18	13	....	127
Mean regarding signs	−6	−4	−8	−6	−2	−12	−1	+2	+6	+4	+2		−4
Mean disregarding signs	±9	±8	±17	±10	±12	±13	±5	±2	±15	±12	±13	±13	±11
Total													
Total no. of days	24	22	32	35	32	46	14	4	16	50	38	14	327
General means regarding signs	+2	−1	−3	−1	−2	0	−2	+2	−8	−3	0	−5	−1
General means disregarding signs	±14	±9	±15	±11	±11	±12	±7	±9	±14	±10	±14	±13	±11

[1] The values are expressed in thousandths of a calory.
* Omitted in means.

Table 5.—*Monthly Mean Values Compared*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920												
No., Harqua Hala....										16	11	4
No., Montezuma										22	25	21
No., in mean....										26	25	22
Mean, Harqua Hala..										1.945	1.952	1.948
Mean, Montezuma ..										1.944	1.948	1.957
Harqua Hala *minus* Montezuma..										.001	.004	—.009
General Mean										1.943	1.948	1.955
1921												
No., Harqua Hala....	13	18	9	15	15	22	11	12	26	23	18	11
No., Montezuma	9	7	12	16	12	17	17	1	5	11	14	12
No., in mean....	16	20	18	26	23	25	25	12	28	27	25	16
Mean, Harqua Hala..	1.964	1.949	1.944	1.948	1.954	1.935	1.939	1.937	1.943	1.944	1.958	1.948
Mean, Montezuma ..	1.955	1.956	1.949	1.944	1.943	1.939	1.947	1.935	1.953	1.946	1.950	1.952
Harqua Hala *minus* Montezuma..	.009	.007	.005	.004	.011	—.004	—.008	.002	—.010	—.002	.008	—.004
General Mean	1.958	1.951	1.946	1.947	1.950	1.934	1.945	1.937	1.944	1.945	1.954	1.950
1922												
No., Harqua Hala....	15	11	13	17	25	25	21	12	21	21	19	14
No., Montezuma	19	9	11	11	5	10	8	10	4	9	8	5
No., in mean....	24	19	21	24	27	26	25	18	22	25	29	16
Mean, Harqua Hala..	1.941	1.947	1.930	1.924	1.928	1.920	1.912	1.920	1.902	1.919	1.921	1.929
Mean, Montezuma ..	1.947	1.942	1.937	1.930	1.924	1.913	1.911	1.918	1.923	1.925	1.925	1.914
Harqua Hala *minus* Montezuma..	—.006	.005	—.007	—.006	.004	.007	.001	.002	—.021	—.006	—.004	.015
General Mean	1.945	1.945	1.934	1.927	1.926	1.919	1.911	1.918	1.904	1.919	1.921	1.925

TABLE 5.—*Monthly Mean Values Compared* (Continued)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1923												
No., Harqua Hala............	17	17	14	17	26	20	....	....	7	18	11	14
No., Montezuma	1	11	27	28	13	23	26	28	28	27	20	17
No., in mean...............	18	20	28	29	29	28	26	28	30	30	25	25
Mean, Harqua Hala..........	1.926	1.916	1.918	1.917	1.923	1.918	....	....	1.925	1.933	1.926	1.925
Mean, Montezuma	1.930	1.912	1.912	1.912	1.916	1.918	1.926	1.931	1.934	1.930	1.931	1.923
Harqua Hala *minus* Montezuma..	−.004	.004	.006	.005	.007	.000	....	....	−.009	.003	−.005	.002
General Mean	1.923	1.918	1.913	1.914	1.920	1.918	1.926	1.931	1.933	1.931	1.929	1.923
1924												
No., Harqua Hala............	26	22	19	19	24	21	11	4	12	24	17	
No., Montezuma	23	16	27	25	26	23	28	18	24	27	26	
No., in mean...............	31	27	30	28	27	28	28	30	27	30	28	
Mean, Harqua Hala..........	1.925	1.918	1.913	1.912	1.920	1.916	1.923	1.926	1.923	1.934	1.934	
Mean, Montezuma	1.931	1.922	1.919	1.917	1.922	1.929	1.922	1.918	1.920	1.929	1.930	
Harqua Hala *minus* Montezuma..	−.006	−.004	−.006	−.005	−.002	−.013	.001	.008	.003	.005	.004	
General Mean	1.927	1.919	1.918	1.916	1.922	1.923	1.922	1.921	1.920	1.931	1.931	
Mean monthly difference H. H. *minus* M. All years combined	−.002 ±.006	.000 ±.005	−.003 ±.006	−.001 ±.005	+.005 ±.006	−.002 ±.006	−.002 ±.003	−.009 ±.011	.000 ±.003	.000 ±.003	+.001 ±.005	+.001 ±.008
Average no. expected {Harqua Hala	16	15	13	16	20	21	9	6	16	21	16	13
good days[1] {Montezuma	16	13	26	25	19	21	26	24	25	24	24	20

[1] These values are not direct means of the numbers of days given above, but taking all known factors into account, they express our best information as to numbers of days in which fairly satisfactory observations may be expected at each station.

yearly period, such as might have been expected from the results of two observatories in opposite hemispheres of the earth. However, the mean values of differences without regard to sign vary considerably from month to month, as would be expected.

Both stations usually have unfavorable weather conditions in December, January, and February, and at Harqua Hala these are also prevalent in March, April, July, August and September. May, June and October are the best months for duplicate observations, and if we had two stations as favorable all the year around as our present
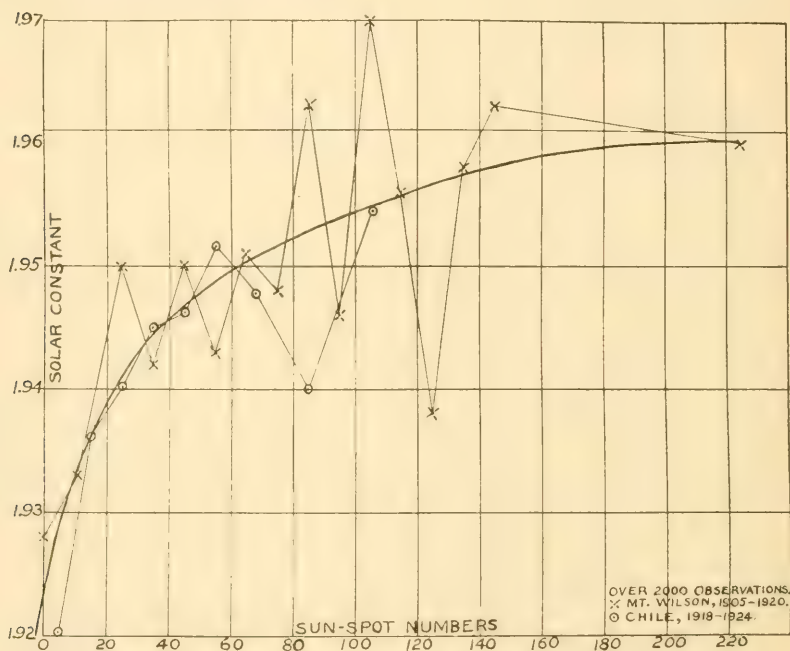
Fig. 2.—Increased solar activity brings higher solar-constant values.

two appear to be in these months, there would be little better to ask for. As conditions are, there is evidently great need of at least two additional first-rate stations, making at least four of them under common management, if really satisfying measurements of the sun's changes are to be obtained.

Unfortunately, the Smithsonian Institution has not the financial means for this. It would require for each new station from $10,000 to $15,000 for original installation, and from $8,000 to $12,000 a year each for continuous operation thereafter, depending on location. It is probable that situations in Africa and in Asia should be chosen, but before selecting them an expenditure of about $5,000 for preliminary investigations of sites should be made.

AN INTRODUCTION TO THE MORPHOLOGY AND CLASSIFICATION OF THE FORAMINIFERA

(WITH 16 PLATES)

BY

JOSEPH A. CUSHMAN

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CONTENTS

FOREWORD

Dr. Cushman's present contribution upon the foraminifera, dealing with the methods of study and other features of general interest, was prepared at the request of the Smithsonian Institution, first as a descriptive account of these minute protozoa, and second as a guide to lessen the work of students who wish to pursue more detailed studies of the class. The foraminifera, which are so abundant in modern seas, were equally prolific during many divisions of geological time, and are ideally constructed for preservation as fossils and for use in stratigraphic geology. However, until recent years the students of the class, employing the methods of study then in vogue, were of the opinion that the specific variability of these organisms was so great as to render them valueless in detailed stratigraphic work, indeed some went so far as to identify present day species in rocks as far back as the Early Cambrian.

Through the efforts of members of the staff and other governmental agencies, the Institution has brought together in the National Museum, great collections of fossil and recent micro-organisms, particularly foraminifera, bryozoa, ostracoda and diatoms, and it has long fostered the scientific study of these collections in the belief that detailed researches would lead to results of great practical value. This belief has been happily justified, and in the case of the foraminifera, Dr. Cushman's work has especially exemplified the economic results arising from purely scientific studies. Not only has he proved from his investigations of the National collections that the species of foraminifera can be discriminated and can be depended upon in sub-surface geologic investigations, but he also has made successful practical applications of his scientific results.

<div align="right">Charles D. Walcott, <i>Secretary.</i></div>

March 23, 1925.

INTRODUCTION

The foraminifera are for the most part microscopic animals living in salt water. There are a few which live in fresh water or under brackish conditions, but they do not develop the typical test and are not found as fossils. The foraminifera belong to the general group of the Protozoa. They are single-celled animals which develop about them a test either of foreign material, which they gather and cement, or usually a calcareous test which is secreted by the animal itself. In the present oceans they occur in enormous numbers, making up a large proportion of the material forming the floors of the oceans at moderate depths. As fossils they have formed limestones thousands of feet thick in various parts of the world. The great pyramids of Egypt are composed of limestones of foraminiferal origin. In the tropical Pacific they occur in such great numbers that they often impede navigation in shoal waters among coral islands.

Until recent years their study has been largely a matter of pure science, and their interest confined, except in a general way to zoologists, to a small group of workers. In the last few years, however, they have assumed an importance for economic work. They occur in great numbers as fossils in most of the Tertiary and Cretaceous strata. Especially in connection with the petroleum industry they have great present and future possibilities. In the drilling of wells most fossils are so broken up that they become unrecognizable in the samples. The foraminifera, however, are usually of such minute size and are in such quantities that enough of them escape the destructive force of drilling so that they form a recognizable part in the well samples themselves. By close study of the section through which a well is drilled it becomes possible to recognize various zones which may be again found in adjacent wells. By such study subsurface maps may be made, which show the geologic features of the underground structures. By this means it is possible to control the placing of additional wells in a field with greater or lesser certainty of increase in production. Where the age of the strata is not definitely known a well may be abandoned before it actually reaches a producing horizon or may pass through such a horizon for a considerable distance without its being recognized. In either case a considerable economic loss results. The knowledge that might have been obtained from the borings is also lost. In many oil fields it is necessary to shut off underground water, and these water horizons may be recognized by a study of the foraminifera. This again is a great economic use of these small fossils.

From this economic aspect there is a great demand for workers on the foraminifera and for literature on the subject. The U. S. National Museum and the U. S. Geological Survey have published a considerable number of papers on the recent and fossil foraminifera of American waters and of the Cretaceous and Tertiary of our own country, based upon collections now in the U. S. National Museum. These form the basis for most of the work that has been done on American foraminifera. Much more needs to be done to describe in detail the many species of our American fossil and recent faunas.

The economic use of the foraminifera is perhaps one of the very best examples of the application of purely scientific work to economic uses. It shows also how valuable are the collections made by such agencies as the U. S. National Museum, the U. S. Bureau of Fisheries, the U. S. Geological Survey and the U. S. Coast and Geodetic Survey. Through these agencies there has been accumulated the great mass of fossil and recent material containing foraminifera which through its study has become of great economic value.

The demand for workers on the foraminifera has made necessary rapid training of numerous students, often where facilities for such study are not available. There are certain requisites which are necessary to a trained worker. Some of these are the study of good material, access to type collections, familiarity with the literature and the knowledge of the group, which can be obtained only after much study. There is a tremendous amount of literature, nearly a thousand books and papers being listed in Sherborn's Bibliography of the Foraminifera published in 1888, which number has since then more than doubled. Except for the papers published by the U. S. Governmental agencies, the U. S. National Museum and the U. S. Geological Survey, there are almost no papers dealing with American fossil and recent foraminifera. A great deal of this earlier literature is European and published in many different languages. Many of the works are available only in a few places in this country. For this reason American students have been greatly handicapped in their work. It is to help in such ways that this present paper is prepared and the rather profusely illustrated publications of the U. S. National Museum and the U. S. Geological Survey have been published. They will many times repay their cost in their economic use to the petroleum industry alone.

GENERAL ACCOUNT OF THE FORAMINIFERA

In the earliest work on this group, these animals were supposed to be molluscs, and to belong to such genera as *Nautilus*. That they

were very low types of animals belonging to the Protozoa was not recognized until much descriptive work had been done upon them. They are now known to form a definite group of the Protozoa, and much is known of the animal as well as the test that it makes about itself.

LIFE HISTORY

Two distinctive forms of many species have been recognized. In general one form is large and rare, the other smaller and much more abundant. Sections of such specimens show that the large form starts with a very small initial chamber or proloculum and is called the *microspheric* form. The small form, on the other hand, commences
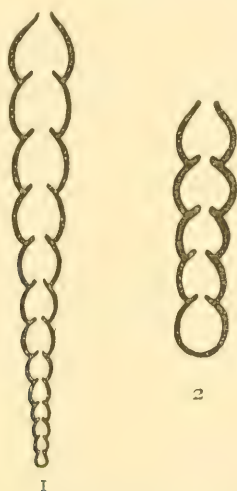
Fig. 1.—Idealized section of microspheric form of Nodosaria showing the small proloculum and the long test.

Fig. 2.—Idealized section of megalospheric form of Nodosaria showing the large proloculum and the short test.

with a much larger proloculum and is known as the *megalospheric* form. Two such sections are shown here, figures 1, 2. It has been discovered that the large microspheric form, when it reaches its adult stage, develops many nuclei, each of which secretes about it a test, and on the breaking down of the "parent" wall these "young" escape into the water and become new animals. This is the typical asexual method of reproduction. The smaller megalospheric form may also do this. Another manner of reproduction may be shown by the megalospheric form, where, when the adult stage is reached, the protoplasm breaks up into a great many very small masses and

escapes from the test in the form of minute free swimming zoospores. These where known are of about the size of the microspheric pro- loculum. From what is known of other groups of Protozoa, these zoospores fuse, and the resulting cell becomes the proloculum of the miscrospheric test. This is sexual reproduction. A true alternation of generations is thus set up not unlike that found in other groups of organisms.

Before the two forms were known, " pairs " of species were de- scribed, as in the case of the Nummulites where a large and small species were often described from the same fossil horizon. These are now known to be the microspheric and megalospheric forms of the same species.

A few species of the foraminifera live at the surface of the ocean and are truly pelagic animals. Almost all of these are species of the Family Globigerinidae. The test is modified by the addition of large pores and large apertures allowing a free passage of the protoplasm to the outside of the test. Most of the pelagic foraminifera tend to assume a spherical form most completely accomplished in *Orbulina*. They occur in enormous numbers in such regions as the Gulf Stream, and their empty tests form a very large proportion of the *Globigerina*- ooze which makes up much of the ocean bottom.

Most foraminifera are bottom-living forms, crawling about on the ocean mud or attached to various objects on the ocean bottom. Their motion is very slow. The most rapid rate I have timed at the Tortugas was in *Iridia diaphana* Heron-Allen and Earland, which travelled at the rate of about 1 centimeter in an hour. As various species must crawl about considerably over the bottom in selecting material for the test, this rate may be slower than the average.

For the most part the food of the foraminifera consists of vegetable matter, minute algæ, etc., with occasionally some of the smaller animal forms, such as copepods, which may be caught in the pseudopodia.

From observations made at the Tortugas, different species have a repellant reaction when they touch one another. From certain specimens it seems that the animal may leave the test at times and either secrete or gather together material for a new and larger test. From the life history and this last mentioned fact, it will be seen that many of the tests of foraminifera are really empty and abandoned tests of full grown individuals. This tends to make an unusual uni- formity in the tests in spite of much of the supposed variation.

STRUCTURE OF THE TEST

In the fresh water foraminifera, which are all of a distinct family from the marine ones, a calcareous or agglutinated test is not developed. What test is formed, is of a gelatinous or flexible chitinous material. In what may be called the more typical forms, the test is either formed by the cementing together of foreign particles or by the secretion of a calcareous test. In the first group, the animal gets its material from the ocean bottom itself. This may consist of the ocean mud, sand, sponge spicules, mica flakes, etc. In some species, a definite selection seems to take place, and one kind of material is used to the exclusion of others. The most striking examples of this are species of *Psammosphaera. P. fusca* Schulze uses only sand grains of various sizes, cementing them into a spherical test. *P. parva* Flint uses sand grains of very uniform size and adds to its test a large acerose sponge spicule projecting at either side. *P. testacea* (Flint) uses the tests of other foraminifera and ignores sand grains which are present in the bottom material. *P. bowmanni* Heron-Allen and Earland makes a test entirely of mica flakes, and *P. rustica* Heron-Allen and Earland of sponge spicules.

Some species of foraminifera which secrete a calcareous test also cover the outside with sand or other fragmental material. These are not true agglutinated tests however, any more than in the case of certain molluscs which cover their shells with fragmental material.

Of the calcareous secreted tests there are two main groups, the perforate and imperforate. In the former the test has great numbers of small pores, while in the latter (Miliolidae) the test is normally without pores and has a peculiar white appearance, whence the name " porcellanous " often applied to the foraminifera belonging to this family. Under brackish conditions and in deep water where calcareous tests are easily dissolved, very thin tests are found of chitinous or even siliceous material.

The test may be simple as in many of the Lagenidae or Rotaliidae, or become complex with internal radiating canals as in the Nummulitidae. In some genera very interesting structures are developed, as in the " balloon " and " float " chambers in *Tretomphalus.*

DEVELOPMENTAL STAGES

As already noted from the habits and life history of the foraminifera, adult tests are the rule in any collection. There are, however, always some specimens which have not yet reached their adult stage and which show development. These stages show definite conformity

to the law of recapitulation, in which an animal repeats in its own development certain of the stages in its ancestry. Thus the test of *Biloculina,* at least in the microspheric form, shows stages comparable to the fully developed characters of *Cornuspira, Quinqueloculina,* and *Triloculina,* before the adult character of *Biloculina* is taken on. In the megalospheric form, certain of these earlier stages are often skipped.

These early stages are important from the point of view of classification. Nearly all the Textulariidae have in the microspheric form a coiled early development closely allied to certain of the Lituolidae, and show that the alternate (Textularian) character was derived through a coiled ancestry.

Likewise in *Peneroplis* and others of the Miliolidae the very earliest stages show a perforate test, and make clear that the imperforate character is an added one and that the Miliolidae are therefore a fairly new group derived from a perforate ancestry. Instead of being a primitive group as earlier thought, the Miliolidae are high in the scale, a fact made further evident by their geologic history.

From the study of developmental stages, coupled with fossil evidence, will come a more sound classification of the group than obtains at present.

VARIATION

From statements made by many of the earlier writers on the foraminifera, it would seem that there is a very great variation in the group. From my own observations this does not seem to hold. In the case of *Ammodiscus incertus,* several hundred specimens were measured, and the amount of variation in respect to size of chamber, size of test and thickness, when reduced to ratio of the size of the initial chamber, was practically negligible. If stages of development are taken into consideration, and the differences due to the microspheric and megalospheric forms are considered, the actual variation left in adults is less than in most other groups of animals. When specific lines are drawn more sharply than at present, as will be done as more material is studied, the variation will be more apparent than real.

DISTRIBUTION IN PRESENT OCEANS

So far as dredging operations have been carried on, the foraminifera seem to be distributed over every part of the ocean bottom. Expeditions into both polar regions have shown that the ocean muds of the polar seas have an abundant foraminiferal fauna. In the shallow water of all the oceans they are abundant. In the deep

ocean basins from the continental shelf out into deep water, *Globi-gerina*-ooze makes up the entire ocean bottom to depths of about 2,000 to 2,500 fathoms. Beyond this depth the ocean bottom consists mainly of red clay. The lack of the calcareous foraminifera in such regions is due to their solution under pressure. In red clay areas numerous species which develop arenaceous tests are characteristic, showing that deep water conditions are in no wise detrimental to the foraminifera.

If material is studied from definite regions, such as I have done for the western Atlantic, it will be found that the foraminifera group themselves into definite faunas just as do other groups of animals in the same regions. The distribution of the shallow water species includes the West Indies, the northern and northeastern coasts of South America, the shores of Mexico and Central America and our own coast as far north as Florida or to the latitude of Cape Hatteras. North of this point an entirely new fauna is found. This continues north to the regions of Nantucket, and further north is replaced by much colder water fauna which is Arctic in character. This is very largely determined by temperature.

The Indo-Pacific shows another fauna which is characteristic of the warmer parts of the Pacific and Indian oceans. A great many species are limited to comparatively shallow water in this region, a few of them extending into the West Indian region. The eastern and western sides of the Atlantic have very different faunas and in general the distribution of species living in shallow water or on continental shelves are as restricted as are those of any other groups. There are two faunas which are widely distributed. These are the pelagic species which are abundant especially in the warmer portions of the oceans like that of the W. Indies and the Gulf Stream, where a very few species occur in great abundance, their empty tests raining down on the sea floor and building up great areas of *Globigerina*-ooze. The distribution of these species on the ocean bottom is determined almost entirely by surface currents and temperatures. Another group, that which lives normally at great depths, is apparently controlled more by temperature than by depth. As a result many of these species occur in all the ocean basins and in cold shallow waters in the temperate or polar regions. These follow the same laws in their distribution as do those of crinoids and other animals which make their home under similar conditions. Very much has yet to be done in determining the geological distribution of the different species, as the tendency has been in the past for most writers not to make close specific determinations.

GEOLOGIC DISTRIBUTION

Foraminifera are known from most of the sedimentary rocks. They occur very abundantly in the Cretaceous and Tertiary of all parts of the world. In the Palaeozoic they seem to be more restricted in their distribution. In the Carboniferous, for example, *Fusulina* forms thick limestones, and various species occur in less abundance in other Palaeozoic formations. Certain groups of foraminifera become abundant and characteristic in certain geologic formations. *Fusulina* and allied forms are very characteristic of certain parts of the Carboniferous. In the Cretaceous the Textulariidae and many Miliolidae become very abundant. The latter probably reaches its highest development in the upper Cretaceous. In the early Tertiary the Nummulitidae become dominant, and form very thick limestones in the Eocene and Oligocene.

It is through the knowledge of the distribution of the various species and genera in various geologic formations that the great economic use of the foraminifera lies. When type sections are known in detail it becomes possible by the study of well cuttings to determine subsurface structure. As a result much is being done in the way of the refinement of the study of fossil forms, and the limits of range of many fossil species. When this work is done thoroughly it makes the foraminifera one of the greatest assets to the geologist in economic work.

METHODS OF HANDLING

RECENT MATERIAL

Collecting.—For systematic work, especially in deep water, it is necessary to have elaborate and rather expensive apparatus. For this reason most of the work in deep waters has to be carried on by governmental vessels, or by especially equipped expeditions for the purpose. Such work was first attempted on any considerable scale by the " Challenger " expedition sent out by the British Government in the seventies, and which explored for four years all the great ocean basins. Since that time many other expeditions have added to the knowledge obtained by the " Challenger." In our country the work of the U. S. Bureau of Fisheries, especially through the numerous voyages of the " Albatross," has resulted in the accumulation of a tremendous amount of material. This has been deposited in the U. S. National Museum, and has been the basis for a considerable amount of literature dealing with the occurrence of the foraminifera, especially of the Pacific, the Philippine region and that of the western Atlantic.

When shallower waters are studied, it is possible for the individual to make very excellent collections. The "bulldog" snappers, which are so devised that they grab up a tea-cup full of the bottom material, can be used from a small boat to a considerable depth. By adding a weight to this apparatus, it is possible to obtain excellent samples, even in two or three hundred fathoms. This method has been used in the West Indies and off the coast of Florida, as well as in the Pacific, with excellent results. It is also possible to obtain a considerable number of foraminifera from beaches where they are often left by the receding tide, in some regions very abundantly.

Preserving.—If it is desirable to study the living animals, it is necessary to preserve them in some form or other. If the cell contents are to be studied special reagents such as are used in general zoological work must necessarily be used. Formaldehyde should not be used as it tends to dissolve the lime content of the tests. As a general preservative, therefore, alcohol is much better. If only the tests are to be studied one of the best methods of preserving the material is to wash it at once in fresh water, and then dry the material, preserving it in bottles or boxes for future use.

Washing.—For the examination of the foraminifera clean tests are necessary. In order to get these the dredged material, which contains mud and fine sand, should be washed. This is best done by means of nested sieves, such as are obtainable at most laboratory supply houses. Brass sieves with meshes of 200, 120, 80, 40, etc., to the inch can be obtained. For more practical purposes sieves with 40 and 80-mesh to the inch are sufficient. The mud is placed directly in the top sieve, and a stream of water with a fine spray played upon the material. If the sieves are shaken so that the material is kept in motion the finer particles will be washed through readily. The resulting clean foraminifera can then be dried. It is sometimes more satisfactory to wash material through the coarsest sieve first into some sort of retainer, and then this again passed through the finer sieves. By this means the finer meshed sieves do not clog with the material.

Sorting.—After the material is washed it often helps in the examination if preliminary sorting can be done. There are different methods of doing this. One is that called "spinning." By this method, the material is put with clean water in a plate or watch glass or in any dish with water so that a circular motion can be set up. This is the old method by which gold was "panned" by the miners. The gold dust was heavier than the sand and came to the middle of the pan. In the case of the foraminifera, however, they, being lighter than the

sand which is with them, accumulate on the outer edges of the material. This can be washed off in the process into a larger receptacle below.

Another method by which rough sorting can be done is by " decanting." If the material is shaken up in a tall vessel of some sort, the lighter specimens will stay in suspension for a short period and can be poured off, leaving the heavier ones on the bottom. Successive stages will separate most of the calcareous tests from the sand and the heavier foraminifera.

One of the most useful methods is that of " floating." The washed material is taken after drying and slightly heated. Then if this heated material is thrown upon cold water those smaller tests, which are filled with air, will float on the surface and can be poured off. In this way beautiful material can be prepared, which is very largely pure foraminiferal tests. This last method combined with " decanting " will give the best results.

Selecting and mounting.—For the study of material containing foraminifera under the microscope, blackened trays are of great service. These may be made by covering the bottom and sides of a shallow pasteboard tray with India ink. When this is scratched another coat can easily be applied. If one wishes to be more elaborate, an excellent tray can be made by placing a piece of black velvet on the bottom of such a tray and covering it with glass. This gives a very intense dull black surface against which the foraminifera stand out to great advantage. Specimens which are to be studied further, or used for future records, must be mounted in some permanent manner. One of the simplest and best methods for this is a slide made of two pieces of pasteboard, for convenience 3 x 1 inches, so that they may be used in ordinary slide boxes. The upper card should have a hole punched in the center and securely pasted to the lower one with a piece of black paper inserted below the circular opening. For additional safety a sheath with the top an ordinary glass slide and the base a thin pasteboard, the glass attached to this by two strips of paper at the sides, may be used. In this the slide with the mounted specimens can be placed, and for ordinary examination it is not necessary to remove the specimens.

In selecting the specimens to be mounted, much the best method is to use a moistened brush. The finest brushes obtainable, oo size, made of red sable bristles are the best. These make a very fine point indeed, and if touched to a specimen can be used to carry it to the slide. The slides themselves should be covered with a gum made of

gum arabic and water with enough glycerine added to prevent crack-
ing. The moistened brush will soften this enough so that the specimen
will be firmly fixed to the surface. If necessary it can be removed very
quickly by again moistening the gum below the specimen with the
brush. Specimens in this way can be mounted in any position for
drawing or photographing, or to show any detail of structure.

Slides are procurable which have a large surface divided into as
many as 100 numbered spaces. These may be used for the different
species of a single locality but are not elastic if a collection is to be
arranged in any systematic way. In the earlier collections of the U. S.
National Museum wooden slides, devised by Dr. Flint, were used.
These were of two different sizes. The specimens were either attached
to the bottom of the cavity or were left loose. They were then
covered with a square of mica, which was held in place by brass
clips. These slides, however, are difficult to arrange well on account
of the clips, and if these become loosened the contents may easily
be lost, the pasteboard slides being much more satisfactory for
general use.

In warm countries it has been found that the ordinary concave glass
slide can be used to advantage, the specimens placed in these and a
glass cover placed over them. This may be held in place in various
ways. The disadvantage of this type of mounting is that specimens
become lodged in the narrow space at the edge of the cell and the
slides, themselves, are easily broken. If the pasteboard slides are
made of reasonably heavy material and paste instead of glue used
they will be found serviceable under almost any conditions.

Needles are sometimes used for picking out specimens, but they are
not elastic, do not retain moisture and are much less satisfactory than
the very fine sable brush already referred to. Camel's hair brushes
are not sufficiently elastic to be of much service.

FOSSIL MATERIAL

Where fossil material can be washed as in the case of many clays,
sands and marls, they can be treated exactly as recent material.
Where the material has become consolidated into hard limestones
very often the only method of studying the contained foraminifera
is through thin sections. These may be prepared in the same manner
as ordinary rock sections. The study of such sections has decided
limitations. They show for the most part the outline in one plane and
something of the details of the internal structure. As most foraminif-
era are determined specifically by their external characters it is next

to impossible to determine the species of most foraminifera from thin sections alone. In the case of certain of the Orbitoid genera such as *Lepidocyclina,* etc., sections are of great importance as many of the specific characters are based on the internal structure.

Unless something is known of the external appearance from other sources it is usually very difficult to even make generic determinations from rock sections. Certainly many of the genera of the Rotalidae cannot be told from one another in section, and the same is true of other groups. It is sometimes possible with hard material to break out whole specimens. This can be done by grinding or by breaking the rock in various ways.

CLASSIFICATION

There have been many classifications since the earliest one of d'Orbigny made in 1826. In most of the works of late years ten families have been recognized, one of these, the Gromidae, being confined largely to fresh water, and not developing the typical test as seen in most other groups of the foraminifera. As these are not preserved in the fossil state and are not usually recognizable in dried material they do not have as much attention paid to them as is given to the rest of the group.

The modern classification is not in any sense a final one but is given here for the purpose of students interested in the group. Various attempts have been made by some authors to group together genera which have a similar form; thus *Ammodiscus,* which is plano-spiral made of cemented sand grains, has been placed in the same family as *Spirillina,* which has a somewhat similar form but with a perforate calcareous test, and also *Cornuspira,* which although the same form has a test calcareous and imperforate. To place in one group different species based solely on the shape of the test does not seen to be a logical method, for, as in many other groups of animals, parallelism is very marked. The structure of the test and the material of which it is made seems to be a much better character than mere form. As more is learned of the various species and genera, it is very probable that the number of families will have to be increased and somewhat new lines of classification adopted. A study of the fossil occurrences of the different genera is very necessary to this as well as the structure of recent forms. For the sake of the students in the group, a few of the descriptive terms commonly used are here given, and a series of simple diagrams.

One of the simplest arrangements of the chambers is that in such coiled bilateral forms as *Nonionina* there are two distinct positions

used in description, the *apertural view* (fig. 3*b*) in the plane of coiling, with the apertural face toward the observer, and the *side view* at right angles to the plane of coiling, the two sides being alike. The *periphery* is the outer edge of the test. The *last-formed chamber* in most foraminifera has the *aperture,* and there is usually developed a distinct *apertural face.* The periphery of the test may have a definite *peripheral-angle* or be *carinate* or *keeled.* The wall of the test may be *perforate* or *imperforate,* and variously ornamented on the exterior. The number of chambers in the last-formed coil is often distinctive.
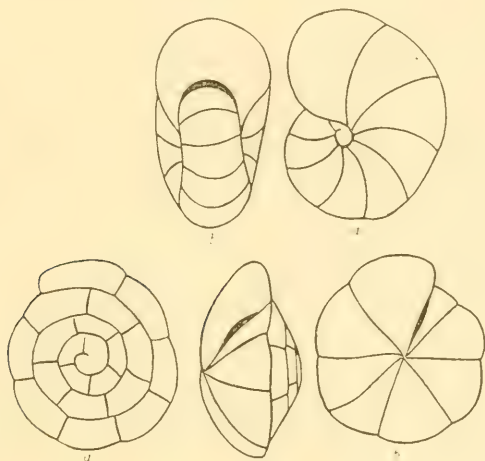
FIG. 3.—A bilaterally symmetrical form of test, showing *a,* side view; *b,* apertural view.

FIG. 4.—A trochoid form showing *a,* dorsal view; *b,* ventral view, and *c,* side or peripheral view.

In the Rotaliidae, particularly, the *trochoid* form of test is common, sometimes called "rotaliform." In this (fig. 4) it is possible to distinguish a *dorsal side* and a *ventral side* (the latter carrying the aperture). The edge view may be spoken of as the *side view* or *peripheral view.* There is a considerable modification, the dorsal side sometimes being the concave one.

In the Lagenidae there may be a *side view* and *apertural view* in such forms as *Lagena* (fig. 5) and *Nodosaria* (fig. 6), and in coiled bilateral forms such as *Cristellaria* (fig. 7), with irregular genera such as *Uvigerina* (fig. 9), and *Polymorphina* (fig. 8), the side views are not all alike.

2

In the Miliolidae, especially such genera as *Quinqueloculina,* the *apertural view* and two *side views* are usually necessary for complete description; one of the latter will show four chambers, the other three. In *Biloculina,* a *front view* and *side view* are frequently used, the latter in the line of the plane of the joining of the two exterior chambers.
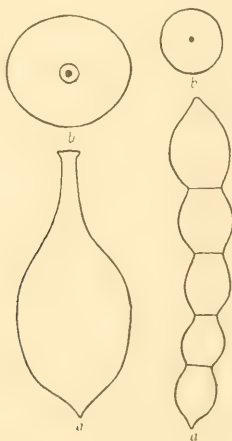
Fig. 5.—*Lagena,* showing *a,* side view and *b,* apertural view. This has a definite neck and phialine lip.

Fig. 6.—*Nodosaria,* showing *a,* side view; *b,* apertural view.
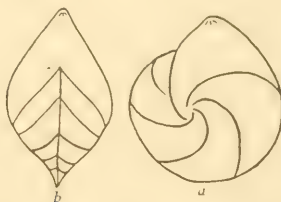
Fig. 7.—*Cristellaria,* showing *a,* side view; *b,* apertural view.

The lines between the chambers on the exterior should be known as *sutures* and the internal walls as *septae.* The initial chamber is known as the *proloculum* and may be either *microspheric* or *megalospheric.* The aperture may be modied by a distinct *tooth* as in many of the Miliolidae (fig. 10), or have a distinct phialine lip as in *Lagena* (fig. 5) or *Uvigerina* (fig. 9).

In many forms such as *Nonionina* (fig. 1), there is a distinct *umbilicus* developed. A study of published figures will give even the beginner a good general idea of the application of most of the descriptive terms used.

There is here given for the benefit of workers on the group an outline of the classification now used, with brief descriptions of the families, subfamilies and many of the genera. There are many more generic names in current use and a very great number now discarded,
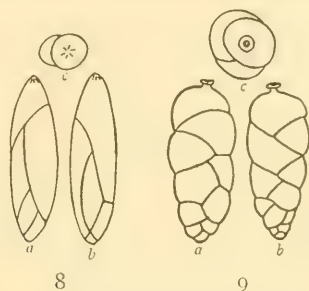
FIG. 8.—*Polymorphina* showing *a* and *b*, two different side views, and *c*, apertural view with radiate aperture.

FIG. 9.—*Uvigerina* showing *a* and *b*, two different views, and *c*, apertural view.
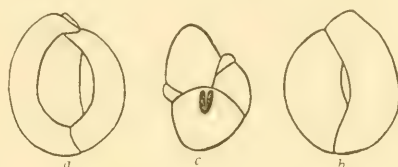
FIG. 10.—*Quinqueloculina* showing *a* and *b*, two different side views; *a*, with four chambers; *b*, the opposite side with but three chambers, and *c*, apertural view, the aperture with a single tooth.
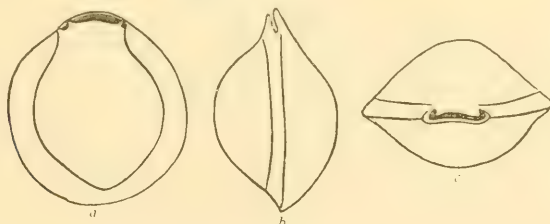
FIG. 11.—*Biloculina*, *a*, front view; *b*, side view; and *c*, apertural view, the aperture with a large broad tooth.

but most of those commonly used will be found here. Most of these have illustrations drawn from the publications of the U. S. National Museum.

Family 1. GROMIDAE

Test membranous or chitinous; aperture if present either single and terminal or one at each end of the test; fresh water or marine. Recent only, no fossils known.

Family 2. ASTRORHIZIDAE

Test composed of agglutinated material for the most part, occasionally with a chitinous inner layer, consisting of a chamber with several openings or a tubular test open at both ends, or in certain forms, of a closed chamber with a single aperture, but throughout the family the test is not divided into a series of chambers.

The species included in this family build tests of agglutinated material, often placed outside a chitinous base as in *Rhizammina, Pelosina,* etc. The simplest species, such as found in the genus *Astrorhiza,* simply gather about the soft parts the mud or débris from the bottom and agglutinate it somewhat with a small amount of cement, the central chamber corresponding to the main part of the cell and the arms to the pseudopodia. Next in order are tests with definite openings and later a test closed all but one point, which serves as the aperture, such as *Pelosina, Pilulina,* etc., or with several apertures, *Thurammina.* From this the series leads to the genera having a definite globular proloculum or initial chamber and a second chamber of greater or less length, *Hyperammina, Ammodiscus,* etc.

Subfamily 1. ASTRORHIZINAE

Test consisting usually of a tube open at both ends or in some species of *Astrorhiza* with several tubes entering a central chamber; in some species with the tube branching.

Genus ASTRORHIZA Sandahl, 1857

Plate 1, fig. 1

Test free, flattened or tubular, composed of sand or mud loosely cemented; chamber within connecting with the exterior by the open ends of the tubes or by several definite apertures in the flattened forms. Most of the species live in deep or cold waters.

Genus RHABDAMMINA Carpenter, 1869

Plate 1, fig. 2

Test free, either radiate, subcylindrical or branching; wall arenaceous usually rather coarsely finished on the exterior, firmly cemented; open ends of the arms serving as apertures. The species are characteristic of deep or cold waters and are widely distributed.

Genus MARSIPELLA Norman, 1878

Plate 1, fig. 3

Test free, tubular, cylindrical or fusiform, sometimes recurved at the ends; wall composed wholly or in part of sponge spicules, or in

part of sand grains, thin, firmly cemented; aperture formed by the open ends of the tube or in some cases closed anteriorly by a loosely aggregated knob of spicules.

Genus BATHYSIPHON G. O. Sars, 1871
Plate 1, fig. 4

Test free, cylindrical, often tapering slightly, straight or more often somewhat curved, in some species externally constricted but not correspondingly constricted internally; wall composed of a base of broken sponge spicules cemented and overlaid with a fine grained apparently siliceous cement, aperture at the ends of the tube.

Genus RHIZAMMINA H. B. Brady, 1879
Plate 1, fig. 5

Test free, consisting of a simple or dichotomously branching, flexible tube; wall largely chitinous, bearing various foreign bodies attached to the exterior.

Subfamily 2. SACCAMMININAE

Test consisting of a single chamber, or group of superficially attached chambers, the walls made up for the most part of agglutinated material; apertures sometimes numerous but usually single; tests free or attached.

Genus PSAMMOSPHAERA F. E. Schulze, 1875
Plate 1, fig. 6

Test free or attached, single chambered, usually spherical, no definite aperture, the pseudopodia making their way out through the interstitial openings between the elements of the test; wall of sand grains, mica flakes, sponge spicules, or other foraminiferal tests firmly cemented.

Genus SOROSPHAERA H. B. Brady, 1879
Plate 1, fig. 7

Test consisting of a colony of more or less inflated chambers, without definite apertures, the walls joined to one another, composed of sand grains with interstitial openings.

Genus DIFFUSILINA Heron-Allen and Earland, 1924

Test sessile, squamous, composed of very finely comminuted sand and mud enveloping a thin labyrinthic layer of chambers. External surface smooth and finished, white to gray in color, furnished with a few sparsely distributed pustules of more loosely aggregated material.

Genus STORTHOSPHAERA F. E. Schulze, 1875

Plate 1, fig. 8

Test free, irregularly rounded, single chambered; wall thick, composed of fine whitish sand very loosely cemented, no visible aperture.

Genus IRIDIA Heron-Allen and Earland, 1914

Test usually attached, consisting of a single chamber lined with a chitinous, transparent membrane, the outer surface consisting of sand grains or other foreign material built up in a dome-shaped test, more or less hemispherical; aperture usually wanting.

Genus RHAPHIDOSCENE Vaughan Jennings, 1896

Test attached, conical, base broad extending to a point at the outer end; chamber single; wall composed of sponge spicules arranged lengthwise of the test with a cement of white calcareous amorphous material; aperture indistinct, at the outer pointed end of the test.

Genus SACCAMMINA Carpenter, 1869

Plate 1, fig. 9

Test typically free, sometimes attached, consisting of a single chamber or of several spherical chambers with distinct apertures, usually one for each chamber; wall composed of sand grains finely cemented by a yellowish or brownish cement; aperture circular, usually with a short neck.

Genus PROTEONINA Williamson, 1858

Plate 1, fig. 10

Test free, consisting of a single undivided chamber, flask shaped or fusiform with a single aperture; wall composed of coarse sand grains, mica flakes, or other foreign material; test usually broadest near the base and gradually tapering more or less evenly to the apertural end; aperture usually circular, with commonly a slight neck which in some species is prominent and extended.

Genus LAGENAMMINA Rhumbler, 1911

Test free, bottle shaped, with a pseudochitinous sublayer on which are laid quite thickly, but roughly, small foreign bodies. The presence of this sublayer distinguishes this genus from *Proteonina,* which does not have such a layer.

Genus PILULINA W. B. Carpenter, 1870

Test free, globular or ovate, consisting of a single undivided chamber; wall composed of felted sponge spicules and a slight amount of fine sand without cement, aperture elongate, with a somewhat depressed area about it.

Genus PELOSINA H. B. Brady, 1879

Plate 1, fig. 11

Test free, variously formed, rounded, cylindrical or irregularly elongate; wall usually thick, composed of mud with various foreign bodies included in the outer portions; interior with a thin, membranaceous, chitinous layer often extending out and forming the whole wall at the apertural end of some species; aperture typically single and terminal, occasionally multiple in P. *variabilis*.

Genus HIPPOCREPINA Parker, 1870

Plate 1, fig. 12

Test free, consisting of a single, elongate, somewhat tapering, straight or slightly curved chamber, closed at the somewhat bluntly pointed proximal end, distal end broad and rounded; walls comparatively thin, of fine sand grains with a reddish-brown cement, grayish toward the distal end; aperture curved, narrow, or irregular, sometimes with a raised lip.

Genus TECHNITELLA Norman, 1878

Plate 2, fig. 1

Test free, usually elongate, subcylindrical, fusiform or elongate oval, consisting of a single chamber; wall thin, composed of sponge spicules and fine sand, aperture rounded at the open end of the test.

Genus WEBBINELLA Rhumbler, 1903

Plate 2, fig. 2

Test fixed, circular in outline, the central portion convex, the peripheral portion often forming a flattened flange-like rim about the central portion; chamber single, undivided; wall of medium thickness, composed of fine sand grains with a large proportion of cement rather smoothly finished both without and within; aperture not apparent, the pseudopodia being thrust out at the basal portion of the test near the surface of attachment.

Genus THOLOSINA Rhumbler, 1895

Plate 2, fig. 3

Test attached, hemispherical, flattened on the side by which it is attached, chamber single, undivided; with pseudopodial extensions of the test along the surface of the attached surface or with the sides clear cut; wall of fine sand grains with a large proportion of calcareous cement; pseudopodial openings at base along attachment or at the end of irregular tubes running out from the base along the surface of attachment.

Genus AMMOSPHAEROIDES Cushman, 1910

Test irregularly subglobular, composed of an elongate or subspherical chamber with double apertures typically; wall finely arenaceous with a large proportion of reddish-brown cement; apertures at the end of short tubular portions of the test.

Genus VERRUCINA Goës, 1896

Test adherent, irregular-ovoid in shape; interior divided into irregular chamberlets; wall composed of sand grains, rough externally; aperture usually double, situated in the depressed area at the center of the dorsal side.

Genus CRITHIONINA Goës, 1894

Test spherical, lenticular or variously shaped, interior either labyrinthic or with a single chamber; apertures small and scattered or indistinct; wall thick, composed of sponge spicules or very fine sand, often chalky in appearance.

Genus THURAMMINA H. B. Brady, 1879

Plate 2, fig. 4

Test typically free, usually nearly spherical, but in some species compressed; chamber single and undivided in typical species; wall thin, composed of fine sand with more or less chitin; apertures several to many at the end of nipple-like protuberances of the surface, occasionally wanting.

Subfamily 3. Hyperammininae

Test consisting of a globular proloculum and a more or less elongated, sometimes branching portion, but not divided into chambers; free or attached; wall of various agglutinated materials.

Genus HYPERAMMINA H. B. Brady, 1878

Plate 2, fig. 5

Test free, elongate, in general a simple cylindrical tube, straight or slightly curved with a swollen proloculum at the proximal end, distal end open and serving as the aperture; wall composed of sand grains, interior usually smoothly finished, exterior often rough, in some species the exterior smoothly finished and the cement in greater excess.

Genus PSAMMATODENDRON Norman, 1881

Test attached by the bulbous proloculum, remainder of test free and erect, dichotomously branching, tubular, of even diameter throughout; wall arenaceous with ferruginous cement; open ends of the tubes serving as apertures.

Genus SACCORHIZA Eimer and Fickert, 1899

Plate 2, fig. 6

Test free, consisting of an ovoid proloculum with a branching tubular second chamber; wall composed of sand grains usually with the exterior roughened by projecting sponge spicules incorporated in the wall; apertures formed by the open ends of the tubular chamber.

Genus SYRINGAMMINA H. B. Brady, 1883

Test free or adherent, consisting of a bulbous base and many branching arms, or of masses of anastomosing tubes in a rounded mass; wall of fine arenaceous particles with a small amount of inorganic cement; apertures at the extremities of the tubular portions.

Genus JACULELLA H. B. Brady, 1879

Plate 2, fig. 7

Test free, elongate, conical, widest at the apertural end, opposite end typically closed; wall comparatively thick, composed of sand grains firmly cemented, rough on the exterior; aperture formed by the open end of the tube, circular,

Genus DENDROPHRYA Str. Wright, 1861

Plate 2, fig. 8

Test attached, consisting of a single chamber, erect or with spreading arms, tubular, irregular or branching; wall arenaceous, with a chitinous base; apertures at the ends of the arms. But a few species

are known and these are largely confined to cold waters at comparatively shallow depths.

Genus HALIPHYSEMA Bowerbank, 1862

Plate 2, fig. 9

Test attached, with an expanded basal portion, and a columnar erect portion either simple or branched ; wall arenaceous, usually with numerous included sponge spicules especially near the tips of the arms or the apertural end of the single chambered species ; aperture at the free end of the chamber or at the ends of the branches, partially obscured by the irregular clustering of spicules.

Genus SAGENINA Chapman, 1900

Test attached, tubular, branching; wall arenaceous; apertures terminal.

Subfamily 4.   AMMODISCINAE

Test composed of a globular proloculum and long, undivided tube, closely coiled, either planospirally or in changing planes or to form a spiral test ; wall of fine sand with much cement, usually of a reddish or yellowish brown.

Genus AMMOLAGENA Eimer and Fickert, 1899

Plate 2, fig. 10

Test firmly attached, composed of an oval proloculum flattened on the under side and a second tubular chamber of variable length but of nearly uniform diameter, the open end serving as the aperture ; wall finely arenaceous, the cement in excess of the sandy particles.

Genus TOLYPAMMINA Rhumbler, 1895

Plate 3, fig. 1

Test typically adherent by its undersurface, but may become free ; consisting of an elongate oval proloculum and a long irregular second chamber, tubular, with nearly even diameter, unbranched ; composed of sand grains and a large proportion of yellowish or reddish brown cement.

Genus AMMODISCUS Reuss, 1861

Plate 3, fig. 2

Test free, planospiral, composed of a globular proloculum and long, undivided tubular second chamber, coiled regularly in one plane ;

wall finely arenaceous, cement yellowish or reddish brown, surface smooth, aperture formed by the open end of the chamber.

Genus AMMODISCOIDES Cushman, 1909
Plate 2, fig. 11

Test free, spiral, initial chamber followed by a coiled nonseptate tube the microspheric form at least, with the early portion forming a hollow cone; later portions becoming broadly flaring usually slightly concave in the opposite direction from that of the early conical portion; wall finely arenaceous, smooth, aperture terminal.

Genus GLOMOSPIRA Rzehak, 1888
Plate 2, fig. 12

Test composed of a subglobular proloculum and long, undivided second chamber, winding upon itself in various planes, not completely spiral throughout; wall finely arenaceous, with a predominance of cement, smooth both without and within, color reddish or yellowish brown.

Genus TURRITELLELLA Rhumbler, 1903

Test free, consisting of a proloculum and long, undivided second chamber, coiled in an elongate, close spiral; wall composed of sand grains and much cement, smooth; aperture, the open end of the tubular chamber.

Family 3. LITUOLIDAE

Test consisting typically of two or more chambers connected with one another, arranged in a linear, planospiral, or trochoid, coiled or irregular series; wall of agglutinated material, the relative amounts of cement and foreign material varying greatly; apertures usually one to each chamber, but sometimes several.

Subfamily 1. ASCHEMONELLINAE

Test composed of agglutinated material, divided irregularly into chambers without definite plan of arrangement.

Genus ASCHEMONELLA H. B. Brady, 1879
Plate 3, fig. 3

Test free, composed of a number of tubular or inflated chambers in a single or branching series, size and form irregular; walls arenaceous, firm, thin; apertures often several at the end of the tubular necks.

Subfamily 2. REOPHACINAE

Test composed of agglutinated material, sand grains, sponge spicules, tests of other foraminifera, etc., with a varying amount of cement; chambers in a linear series; aperture usually single and at the distal end of the chamber but occasionally at the side, rarely multiple or cribrate.

Genus REOPHAX Montfort, 1808

Plate 3, fig. 4

Test free, composed of chambers in a linear series, usually joined end to end in a straight or slightly curved line, ranging from closely overlapping chambers to remotely separated ones with stoloniferous connections between; chambers few or numerous; wall of sand grains, mica scales, sponge spicules, chitinous or of tests of other foraminifera; chambers undivided, aperture simple, terminal, at the distal end of the last-formed chamber.

Genus HORMOSINA H. B. Brady, 1879

Plate 3, fig. 5

Test free, composed of a linear series of subglobular, fusiform, or pyriform chambers joined end to end in a single moniliform series, straight, somewhat curved or irregular; walls usually thin, finely arenaceous with an excess of cement; chambers undivided; aperture a single circular opening usually at the dorsal end of the last-formed chamber, often with a neck, but occasionally at the side of the chamber; color yellowish or reddish brown.

Genus HAPLOSTICHE Reuss, 1861

Plate 3, fig. 6

Test free, cylindrical or tapering, composed of a linear series of chambers, interior labyrinthic; walls thick, coarsely arenaceous, but usually fairly smooth on the exterior; aperture terminal in the middle of the distal portion of the last-formed chamber, in the earlier chambers usually simple, in the adult made up of several pores or in large specimens often dendritic, occasionally with a short neck.

Subfamily 3. TROCHAMMININAE

Test composed of several chambers, either in a planospiral coil, trochoid, or otherwise arranged; wall composed of sand grains of varying degrees of coarseness cemented with a calcareous or ferruginous cement, free or attached.

Genus TROCHAMMINOIDES Cushman, 1910

Plate 3, fig. 7

Test free, typically planospiral, composed of several coils, each constricted into a number of chamber-like portions with the openings between large; wall of fine sand and a yellowish-brown cement; aperture simple at the end of the last-formed chamber.

Genus HAPLOPHRAGMOIDES Cushman, 1910

Plate 3, fig. 8

Test free, planospiral, composed of several coils, each composed of a number of chambers; wall arenaceous, varying much in texture and in the relative amount of cement in the different species; aperture at the ventral border or on the lower portion of the apertural face of the chamber.

Genus CRIBROSTOMOIDES Cushman, 1910

Plate 4, fig. 1

Test free, planospiral, composed of numerous chambers in several coils, the last-formed coil with several chambers progressively increasing in size; wall arenaceous, with much cement usually of a light brown color; aperture in young specimens a simple elongate slit at the base of the apertural face, later subdivided by tooth-like processes, and in the adult represented by a linear series of distinct rounded openings.

Genus CYCLAMMINA H. B. Brady, 1876

Plate 3, fig. 9

Test free, planospiral, composed of numerous chambers in a close-coiled involute series, final volution usually embracing the preceding ones except at the umbilicus; walls thick, composed of fine arenaceous material with a large amount of reddish-brown cement, exterior smooth; chambers with secondary labyrinthic structures interiorly, especially on the peripheral portion of each chamber, early chambers often becoming completely filled by this secondary growth; aperture a curved fissure at the proximal portion of the apertural face, supplemented by numerous pores in the central portion of the apertural wall.

Genus LOFTUSIA Carpenter and Brady, 1869

Test of large size, spiral; elongated in the direction of the axis; fusiform or elliptical; resembling *Alveolina* in contour.

Genus LITUOTUBA Rhumbler, 1895

Plate 4, fig. 2

Test of two distinct parts, an early close-coiled portion and a long tubular uncoiled later portion; wall arenaceous, with an excess of cement, either indistinctly or irregularly divided.

Genus AMMOBACULITES Cushman, 1910

Plate 4, fig. 3

Test free, composed of several chambers, early portion close coiled in a single plane, later portion uncoiled and made up of a more or less linear series of chambers; wall coarsely arenaceous, usually rather thick; aperture single at the distal end of the last formed chamber in the adult uncoiled specimen, but in the young usually at the base of the apertural face.

Genus HAPLOPHRAGMIUM Reuss, 1860

Test in the early portion close coiled, planospiral, later becoming uncoiled and straight; chambers distinct, not labyrinthic; wall arenaceous; aperture in the adult consisting of a number of pores, the apertural face often becoming sieve-like.

Genus LITUOLA Lamarck, 1804

Plate 4, fig. 4

Test crozier-shaped, the early portion planospiral, the later portion uncoiled and straight, test arenaceous, the chambers labyrinthic with radial vertical partitions and secondary septæ; aperture typically of several pores.

Genus PLACOPSILINA d'Orbigny, 1850

Test attached, composed of numerous chambers, the early portion close-coiled, later portions uncoiling and spreading out in an irregular but in general a linear series of chambers, building no floor; last portion of the test may be entirely free, made up of an irregular series of chambers; wall coarsely arenaceous, aperture rounded, at the end of the last-formed chamber.

Genus ROTALIAMMINA Cushman, 1925

Test rotaliform, attached by the ventral side, all chambers visible from above, only those of the last-formed coil from below, chambers numerous with thick arenaceous walls of matted spicules, the areas between softer and somewhat flexible; aperture ventral, along the growing edge of the test.

Genus TROCHAMMINA Parker and Jones, 1860

Plate 4, fig. 5

Test free or sometimes adherent, spiral, trochoid, chambered; all chambers visible when viewed from above, only the chambers of the last-formed volution visible from below; wall arenaceous usually with considerable cement; aperture an arched slit on the ventral side of the chamber at its contact with the preceding volution.

As here considered, *Trochammina* is restricted to those species like *T. inflata* (Montagu) or *T. squamata* Jones and Parker, which have a true spiral, trochoid test with all the chambers visible only from above.

Genus GLOBOTEXTULARIA Eimer and Fickert, 1899

Plate 4, fig. 6

Test arenaceous, the early chambers in a spire, the later ones irregular, globular, Globigerina-like.

Genus AMMOCHILOSTOMA Eimer and Fickert, 1899

Plate 3, figs. 10, 11

Test free, early chambers spiral, later ones very involute, and the last-formed volution often entirely covering the previously formed chambers and usually at an oblique angle to the earlier growth; wall arenaceous, with a variable, usually excessive amount of cement; aperture at or near the base of the apertural face of the chamber, elongate, narrow, color usually reddish or yellowish brown.

Genus AMMOSPHAEROIDINA Cushman, 1910

Plate 4, fig. 7

Test globose, arenaceous, early portion spiral, later chamber like *Sphaeroidina* in form, embracing; aperture rounded, at one side of the chamber in the adult.

Genus SPHAERAMMINA Cushman, 1910

Test composed of a series of chambers, the last one formed completely enveloping the preceding ones, but the axis straight; wall arenaceous.

Genus AMMOSPHAERULINA Cushman, 1912

Test spherical, adherent; wall arenaceous; composed of two or more chambers, each included by the one next-formed, eccentric; color light yellowish-brown.

Genus NOURIA Heron-Allen and Earland, 1914

Test free, composed of several chambers, in a generally *Polymorphina*-like arrangement; wall arenaceous or composed of sponge spicules; sutures indistinct; aperture terminal.

Subfamily 4. NEUSININAE

Test arenaceous with some chitin, flattened and broad, composed of many chambers, early portion coiled with the later chambers broad and spreading, sides with elongate chitinous filaments.

This subfamily containing the single species, *Neusina agassizii* Goës, is different from the other arenaceous foraminifera but in its general plan of structure is not unlike certain other genera.

Genus NEUSINA Goës, 1892

Test expanded, flat, made up of a series of very broad, low, flattened chambers, early ones in complete specimens apparently coiled, later ones in a broad, flat expanse of varying shape; wall arenaceous or of fine mud and sand with a chitinous network, flexible with a thread-like border of chitin; apertures numerous, along the edge of the chamber; color in fresh specimens brown.

Genus BOTELLINA, W. B. Carpenter, 1869

Test arenaceous, cylindrical, one end rounded and more or less swollen; walls of the test of firm consistence, rough, subdivided irregularly by a labyrinth of sand grains cemented together at various angles forming rude chamberlets which open out into a main tube or chamber, which runs through nearly the whole test.

Subfamily 5. ORBITOLININAE

Test siliceous, imperforate, crateriform and composed of concentric annuli which are partitioned off into numerous chambers.

Genus ORBITOLINA Lamarck

Test conical, usually broader than high, base flattened or often concave, chambers numerous divided into chamberlets; a central mass of chamberlets more or less compressed with the walls usually labyrinthic; base with numerous apertures.

Genus CONULITES

Test conical, usually higher than broad, base flattened or convex, early chambers spiral, outer chamberlets rectangular; walls straight; internal chamberlets usually in curved layers; apertures in the basal wall.

Subfamily 6. ENDOTHYRINAE

Test arenaceous with calcareous cement wall distinctly perforate.

Genus NODOSINELLA Brady, 1876

Test Nodosariform, finely arenaceous, nearly smooth externally; interior sometimes slightly labyrinthic; aperture simple.

Genus STACHEIA Brady, 1876

Test adherent, composed either of numerous segments subdivided into chamberlets, or of an acervuline mass of chamberlets either arranged in layers or confused.

Genus ENDOTHYRA Phillips, 1846

Test polythalamous; nautiloid or Rotaliform; aperture simple, situated at the inner margin of the final chamber.

Genus BRADYINA Möller, 1878

Test nautiloid; aperture consisting of a number of pores on the face of the terminal chamber; with pores (?) also in the septal depressions.

Genus INVOLUTINA Terquem, 1862

Test lenticular, consisting of a planospiral tube with a deposit of shell-substance on both faces, thickest near the middle; tube sometimes slightly constricted at intervals; shell-wall more or less perforate.

Family 4. TEXTULARIIDAE

Test either arenaceous or calcareous, perforate, the chambers usually numerous, typically biserial or triserial, or in some genera spirally arranged.

Subfamily 1. SPIROPLECTINAE

Test either coarsely arenaceous or calcareous, or even hyaline, the early chambers following the proloculum closely coiled, the later

3

chambers biserial, occasionally tending to become uniserial in the last developed chambers.

Genus SPIROPLECTA Ehrenberg, 1844

Plate 4, fig. 8

Test with the early chambers close-coiled in both the microspheric and megalospheric forms; later chambers biserial; wall typically arenaceous.

Subfamily 2. TEXTULARIINAE

Test typically biserial, wholly or in part, the early portion in the microspheric form often with a few coiled chambers, followed by the biserial chambers; later chambers variously modified in the different genera, uniserial, broadly extended, etc.; wall either arenaceous or calcareous and hyaline, perforate; aperture single, or in a few cases, many present in a single chamber.

Genus TEXTULARIA Defrance, 1824

Plate 5, fig. 1

Test elongate, tapering, composed of two series of alternating chambers; wall calcareous in the young, hyaline and perforate, occasionally so throughout the test, often with an external coating of siliceous or calcareous sand, or in some species nearly the whole test arenaceous; aperture typically an arched slit at the inner margin of the chamber close to its line of attachment to the preceding chamber; occasionally with the aperture surrounded by a raised lip, or in some species with the aperture circular and terminal.

Genus TEXTULARIOIDES Cushman, 1911

Test attached, consisting of a *Textularia*-like series of chambers, arranged in two series, the chambers of one series alternating with those of the other; wall arenaceous; aperture an elongated slit in a depression at the base of the inner margin of the chamber.

Genus BIGENERINA d'Orbigny, 1826

Plate 4, fig. 9

Test free, generally elongate, cylindrical or compressed, the early portion textularian, composed of a series of biserially arranged chambers, later chambers arranged in a single line; wall usually thick, arenaceous, usually coarse but often smoothly finished; aperture in

the young at the base of the inner margin of the last-formed chamber, as in *Textularia,* but in the adult, in the uniserial portion terminal, rounded or oval according to the form of the chamber.

Genus CLIMACAMMINA H. B. Brady, 1876

Test arenaceous with a calcareous base, early chambers biserial, later ones uniserial; aperture of numerous rounded pores.

Genus BOLIVINA d'Orbigny, 1839

Plate 4, fig. 10

Test elongate, distinctly biserial throughout; wall usually thin and hyaline in the young, but becoming thickened with age in many species, ornamented by punctæ, striæ, costæ, knobs, and spines, with carinæ developed in some species; aperture elongate, usually symmetrical.

Genus PLEUROSTOMELLA Reuss, 1860

Plate 5, fig. 2

Test elongate, somewhat compressed, composed of numerous chambers, usually biserially arranged; wall calcareous, perforate, smooth or ornamented; aperture distinctive, an arched opening with a vertical notch or slit in the middle of the lower edge usually with tooth-like projections upward at either side.

Genus PAVONINA d'Orbigny, 1826

Plate 5, fig. 3

Test calcareous, hyaline, perforate, many chambered, the early chambers biserial, the later ones becoming uniserial, broad, curved, in the type species finally becoming embracing, and the embracing series each composed of one or more chambers; apertures numerous on the peripheral margin.

Genus CUNEOLINA d'Orbigny, 1839

Test biserial, tapering, broadest near the apertural end, compressed so that the two alternating series of chambers form a zigzag line on the narrow sides of the test; chambers numerous, low, and very broad, wall arenaceous, composed of very fine material, smooth, chamber wall labyrinthic, composed of numerous openings, the smaller near the exterior; aperture elongate, narrow, either simple or a row of pores.

Genus BIFARINA Parker and Jones, 1872

Test with the early chambers like *Bolivina* but in later development becoming uniserial.

Subfamily 3. VERNEUILININAE

Test with the early chambers triserial, in some genera later becoming biserial or uniserial.

Genus VERNEUILINA d'Orbigny, 1840

Plate 5, fig. 4

Test free, more or less elongate, tapering, in cross section round or triangular, composed of a series of chambers spirally arranged, but in three vertical columns ; walls variable, arenaceous or hyaline ; aperture a slit at or near the base of the inner margin of the chamber.

Genus VALVULINA d'Orbigny, 1826

Plate 5, fig. 5

Test spiral, conical, with three chambers in a whorl, umbilicate, usually attached ; wall arenaceous, fairly smooth ; aperture provided with a valvular tooth ; color usually reddish-brown, area of fixation white or light gray.

Genus CHRYSALIDINA d'Orbigny, 1846

Plate 5, fig. 7

Test many chambered, triserial, at least in the early portion, tapering ; apertures numerous, scattered over the terminal wall of the chamber ; other walls also porous.

Genus TRITAXIA Reuss, 1860

Plate 5, fig. 6

Test triserial, at least in the earlier portion, usually triangular in cross section ; aperture central and terminal with or without a distinct neck and lip, rounded ; wall usually arenaceous.

Genus GAUDRYINA d'Orbigny, 1839

Plate 6, fig. 1

Test free, composed of two distinct portions, the earlier consisting of a series of chambers arranged triserially, followed by a later portion consisting of a series arranged biserially ; wall arenaceous,

varying much in coarseness in the different species ; aperture variable as in the various species of *Textularia,* either an opening at the base of the inner margin of the chamber, between it and the wall of the preceding chamber, or a perforation near the base of the inner margin, often with a raised border, or in some species a terminal more or less circular opening.

Genus TRITAXILINA Cushman, 1911

Plate 6, fig. 2

Test in its early development triserial, later becoming biserial and in the adult uniserial; chambers numerous, distinct, interior labyrinthic ; wall arenaceous ; aperture in the triserial portion elongate with a valvular lip, at the edge of the inner side of the chamber, in the adult central, terminal, usually with a series of peripheral teeth projecting in and partially closing the opening.

Genus CLAVULINA d'Orbigny, 1826

Plate 7, fig. 1

Test free, elongate, cylindrical or angled ; early portion consisting of a number of chambers arranged triserially ; later portion consisting of numerous chambers arranged uniserially ; walls arenaceous, usually smooth ; aperture in early chambers with a valvular tooth ; in the later portion aperture central or nearly so, rounded, and with or without a tooth.

Genus MIMOSINA Millett, 1900

Test triserial ; wall thin ; aperture of two openings, one a slit at the base of the ventral face, the other varying in shape and near the outer end of the ventral face ; the two sometimes connected on the interior of the test.

Subfamily 4. BULIMININAE

Test elongate spiral ; wall usually hyaline at least in the early stages, calcareous ; perforate ; aperture typically a comma-shaped slit.

Genus BULIMINA d'Orbigny, 1826

Plate 5, fig. 8

Test usually fusiform or tapering, free, composed of numerous chambers arranged typically in a spiral, each chamber situated above the third preceding one, making a triserial arrangement, not always

visible from the surface except in the last convolution; wall calcareous, perforate, usually thin and transparent, but thickening somewhat with age, smooth or ornamented with raised costæ, spines, etc.; aperture typically a comma-shaped slit broadest above and tapering obliquely to a point below, usually with a raised margin and often partly closed by a tooth-like rim at one side.

Genus BULIMINELLA Cushman, 1911

Plate 6, fig. 3

Test composed of chambers triserially arranged, but in later development becoming involute and spirally coiled, the aperture being in the umbilicus thus formed; wall calcareous, perforate; aperture in the species but little twisted spirally, long and narrow, nearly vertical, in the closely spiral species becoming rounded in the middle of the concave umbilical area.

Genus BULIMINOIDES Cushman, 1911

Plate 7, fig. 2

Test triserial, spiral, elongate, subcylindrical; wall calcareous, perforate; aperture nearly circular, terminal, in a depression of the truncated apertural end.

Genus VIRGULINA d'Orbigny, 1826

Plate 6, fig. 4

Test elongate, tapering, typically biserial, often becoming irregularly twisted in a spiral manner; chambers distinct; sutures usually depressed; wall calcareous, thin and translucent, in adults sometimes becoming thicker and opaque, perforate; aperture typically a comma-shaped opening with the narrow end coming to the base of the chamber; color white.

Subfamily 5. CASSIDULININAE

Test both spiral and biserial, the early chambers somewhat spirally placed, the later ones biserial; wall usually hyaline and perforate; aperture comma-shaped.

Genus CASSIDULINA d'Orbigny, 1826

Plate 6, fig. 5

Test complex, at least the early portion coiled, the chambers arranged biserially, alternating on the sides of the axis of coiling,

chambers usually extending to the umbilicus on the sides, in some species the later portion of the test uncoiling; wall calcareous, perforate, usually smooth and without ornamentation; chambers numerous, the sutures usually distinct; aperture loop-like, modified in breadth and length in the different species.

Genus EHRENBERGINA Reuss, 1850

Plate 6, fig. 6

Test free, early portion coiled, later portion uncoiled, composed of numerous chambers arranged biserially about an elongate axis, evenly united on the dorsal side but forming a deep groove on the ventral border, generally triangular in cross section; wall calcareous, perforate, smooth, or ornamented with spines or ridges; aperture elongate, curved, nearly at right angles to the edge of the chamber, with a slight lip.

Family 5. LAGENIDAE

Test calcareous, vitreous, finely perforate, either monothalamous or made up of a series of chambers arranged in a straight or curved axis, or close-coiled or spirally, or even in an alternating manner; aperture either radiate or simple or with a neck and phialine lip.

Subfamily 1. LAGENINAE

Test consisting of a single chamber, the aperture either ecto- or entosolenian.

Genus LAGENA Walker and Boys, 1784

Plate 6, fig. 7

Test monothalamous, smooth or ornamented, generally flask-shaped; aperture ecto- or entosolenian.

Subfamly 2. NODOSARIINAE

Test polythalamous; chambers arranged in a straight, arcuate, planospiral or uncoiling series; apertures either radiate or with neck and phialine lip.

Genus NODOSARIA Lamarck, 1812

Plate 7, fig. 3

Test composed of a straight or arcuate series of chambers, either loosely joined together by stolons or close set and overlapping or

various forms between; surface smooth or ornamented; aperture either radiate or with a definite neck and phialine lip.

Genus LINGULINA d'Orbigny, 1826

Plate 7, fig. 4

Test compressed; chambers arranged in a linear series, usually closely set; aperture usually elongate, corresponding to the form of the chamber.

Genus TRIFARINA Cushman, 1923

RHABDOGONIUM H. B. Brady, not Reuss

Plate 7, fig. 5

Test elongate, triangular in transverse section; the early chambers in an irregular spiral, later ones very loosely so or even uniserial; wall thin, translucent, finely punctate; aperture terminal not radiate, at the end of a short, often phialine lip.

Genus CRISTELLARIA Lamarck, 1812

Plate 8, fig. 1

Test planospiral, typically close-coiled, but becoming much uncoiled in some species; chambers numerous; wall hyaline, perforate, variously ornamented; aperture usually distinctly radiate.

Genus MARGINULINA d'Orbigny, 1826

Plate 7, fig. 6

Test subcylindrical, early portion close-coiled, later chambers uncoiled, rounded in transverse section, the last-formed chambers often inflated; aperture in early chambers marginal, later often becoming nearly median, usually radiate.

Genus VAGINULINA d'Orbigny, 1826

Plate 8, fig. 2

Test elongate; chambers in a linear series, placed so that the sutures are oblique; aperture marginal; chambers laterally compressed.

Genus FRONDICULARIA, Defrance, 1824

Plate 6, fig. 8

Test compressed, in the adult consisting of chambers, elongate and narrow, running back on either side of the test; wall vitreous, finely

perforate; aperture single, either radiate or surrounded with a lip which is usually cut in a radial manner; surface smooth or ornamented with costæ; microspheric specimens with a coiled development in the earlier chambers; megalospheric specimens without the coiled chambers as a rule.

Subfamily 3. POLYMORPHININAE

Test polythalamous; chambers usually arranged in an irregular spiral, in later growth sometimes approaching a biserial arrangement or sometimes uniserial; surface smooth or ornamented by spines or costæ; aperture radiate.

Genus POLYMORPHINA d'Orbigny, 1826

Plate 7, fig. 8

Test more or less rounded, usually not equilateral; chambers few, obliquely placed in a more or less spiral arrangement; aperture terminal, radiate; wall calcareous, perforate, either smooth or variously ornamented with spines, costæ, or tubercles.

Genus DIMORPHINA d'Orbigny, 1826

Test with the early chambers polymorphine, later ones uniserial.

Subfamily 4. UVIGERININAE

Test composed of several chambers, typically spirally arranged, especially in the earlier portion, later chambers often becoming loosely arranged, or even uniserial; wall smooth or variously ornamented; aperture typically consisting of a neck with a definite phialine lip.

Genus UVIGERINA d'Orbigny, 1826

Plate 8, fig. 3

Test elongate, spiral, consisting of numerous chambers, usually arranged triserially, occasionally in later growth with fewer than three chambers in each volution; wall calcareous, perforate, hyaline, smooth or ornamented with spines or costæ or modifications of them; aperture with usually a tubular neck at the end of which is a phialine lip.

Genus SIPHOGENERINA Schlumberger, 1883 (SAGRINA of Authors, not d'Orbigny)

Plate 8, fig. 4

Test elongate, composed at least in the microspheric form of a series of chambers arranged tri- or bi-serially, followed by a later uniserial development; walls hyaline and perforate; aperture in the uniserial portion central and terminal, usually with an elongated neck and flaring lip; interior of the chamber with a tubular connection running from the base of the apertural neck to the lip of the aperture below; wall smooth or ornamented by costæ, pits, etc.

Subfamily 5. RAMULININAE

Test composed of branching tubular masses with rounded chamber-like portions at irregular intervals.

Genus RAMULINA Rupert-Jones, 1875

Plate 8, fig. 5

Test free, branching, consisting of more or less rounded chambers connected by long stoloniferous tubes; wall hyaline.

Genus VITREWEBBINA Chapman, 1892

Test attached, composed of a series of rounded chambers increasing in size as added, usually in a curved line; test finely perforate; aperture a small arched opening at the base of the last-formed chamber.

Family 6. CHILOSTOMELLIDAE

Test calcareous, conspicuously punctate, chambers usually somewhat inflated, irregularly coiled, the last-formed chamber in the various genera making up a large portion of the last-formed volution; aperture usually a curved opening between the base of the chamber and its predecessor, sometimes terminal.

Genus CHILOSTOMELLA Reuss, 1850

Plate 8, fig. 6

Test composed of a series of chambers in a coil, each chamber making a half coil of 180° and embracing so that but a small part of the preceding chamber is visible from the exterior; wall smooth, finely perforate, either thin and transparent or thick and opaque; aperture at the inner margin of the ventral face of the chamber curved, often with a slightly upward-turned lip.

Genus ALLOMORPHINA Reuss, 1850
Plate 7, fig. 7

Test made up of a few ovate chambers in a coil, each chamber making up 120° of the volution so that but three chambers are visible from the exterior; wall thin, translucent, finely punctate; aperture a narrow slit at the base of the chamber.

Genus SEABROOKIA H. B. Brady, 1890

Test composed of a series of chambers, each partially or entirely inclosing the preceding one; wall thin, hyaline, perforate; aperture terminal, rounded, with a slightly thickened lip.

Genus ELLIPSOIDINA Seguenza, 1859

Test uniserial, each chamber added from the base of the preceding one and entirely enclosing it; aperture terminal with a projecting lip, often connected interiorly by a tubular neck with the preceding aperture.

Family 7. GLOBIGERINIDAE

Test composed of numerous chambers, usually much inflated, arranged typically in a trochoid coil, but in some species becoming planospiral; often umbilicate; wall calcareous and perforate, usually with a more or less regular reticulation and in perfect specimens in some species with long slender spines; aperture either large and simple or with numerous accessory openings.

Genus GLOBIGERINA d'Orbigny, 1826
Plate 8, fig. 7

Test composed of numerous inflated chambers arranged typically in a trochoid manner, but which in later development may be variously arranged; wall typically coarsely perforate, reticulate; aperture large, arched, at the base of the inner margin of the chamber, in some species opening on the umbilicus, in others with numerous accessory openings.

Genus ORBULINA d'Orbigny, 1839
Plate 8, fig. 8

Test in the early stages composed of several *Globigerina*-like chambers rapidly increasing in size as added, finally entirely surrounded by the adult chamber which is spherical, with numerous small pores, and one large circular orifice, or occasionally more than one; wall reticulated, in living condition with long, fine spines.

Genus HASTIGERINA Wyville Thomson, 1876

Plate 8, fig. 9

Test composed of numerous chambers arranged in a planospiral manner, inflated; surface with numerous spines, the edges parallel and toothed; aperture large, broad, oval, at the inner margin of the chamber.

Genus CANDEINA d'Orbigny, 1839

Plate 9, fig. 1

Test generally trochoid, usually with the spire somewhat compressed and the later chambers often irregular; chambers numerous, rapidly increasing in size as added, inflated; wall usually clear and translucent, in old-age specimens occasionally thickened and opaque; apertures numerous, elliptical in form, placed in a somewhat regular manner along the sutural lines between the chambers.

Genus SPHAEROIDINA d'Orbigny, 1826

Plate 9, fig. 2

Test composed of a few chambers arranged in an irregular spire, the later chambers especially much inflated, increasing rapidly in size and embracing, a few only visible from the exterior; wall perforate; aperture an arched opening at or near the inner margin of the chamber, often with a calcareous, tooth-like process partially closing the opening.

Genus PULLENIA Parker and Jones, 1862

Plate 9, fig. 3

Test composed of several chambers arranged in a planospiral or oblique nautiloid more or less involute spiral, chambers not greatly inflated, only those of the last-formed volution visible; wall smooth, perforations small and indistinct; aperture a curved opening at the base of the inner face of the chamber.

Genus HANTKENINA Cushman, 1924

Test free, planospiral, consisting of about three coils, chambers few, usually about five in the adult coil, laterally compressed, wall finely or coarsely perforate, sutures distinct and depressed, each chamber, at least in the adult, with a stout peripheral spine with a hollow center, aperture tripartite, one arm running along either side of the base of the chamber, the other extending peripherally in the apertural face of the chamber.

Family 8. ROTALIIDAE

Test calcareous, perforate, composed usually of numerous chambers, except in the subfamily Spirillininae, early chambers coiled, and later chambers in typical genera spirally coiled so that the chambers are all visible from the dorsal side and only those of the last formed coil from the ventral side, convexity of the two sides varying greatly; later development in specialized genera being columnar or even arborescent.

Subfamily 1. SPIRILLININAE

Test free or attached, composed of a proloculum and a long coiled tubular second chamber; variously ornamented; aperture at the end of the tube; wall calcareous, perforate.

Genus SPIRILLINA Ehrenberg, 1841

Plate 8, fig. 10

Test typically free, occasionally attached, spiral, composed of a subcircular or ovoid proloculum and a long undivided tubular second chamber, coiled regularly in one plane; wall hyaline and perforate; surface smooth or variously ornamented; aperture formed by the open end of the tube.

Subfamily 2. ROTALINAE

Test spiral, rotaliform, rarely evolute, very rarely irregular or acervuline; chambers numerous, distinct or in some few species largely obscured by shell growth, early chambers in all distinctly rotaliform.

Genus PATELLINA Williamson, 1858

Plate 9, fig. 4

Test conical in form or plano-convex; the early chambers spirally arranged, later ones long and becoming annular or nearly so about the periphery; chambers of living forms usually simple but often patially divided by internal septæ, visible from the exterior; aperture elongate, at the inner border of the chamber.

Genus DISCORBIS Lamarck, 1804 (DISCORBINA of Authors)

Plate 10, fig. 1

Test free or attached, spiral and rotaliform, plano-convex or biconvex, or modified variously in different species; typically plano-convex with the ventral side flattened and the dorsal convex; all cham-

bers visible from the dorsal side, only those of the last-formed coil visible from the ventral side; test composed of several coils, usually three or four in the adult test; chambers rather numerous; aperture a slit at the umbilical margin of the ventral side of the chamber.

Genus CYMBALOPORA Hagenow, 1850

Plate 10, fig. 2

Test free, early chambers spirally arranged, later ones annular or irregular; umbilicate; wall finely perforate; chambers as added often not contiguous, but separated from one another by some distance along the periphery, marked on the ventral side by depressions radiating from the central umbilicus; in the various species the early chambers following the proloculum are usually brownish in color, this being wanting in the later adult chambers.

Genus TRETOMPHALUS Moebius, 1880

Plate 10, fig. 3

Test free, early stages *Discorbis*-like, in a low conical spire; last formed chamber globular, larger than the entire early growth; wall perforate, the last formed chambers with very large ones; aperture in adult chamber rounded with an entosolenian neck.

Genus PLANORBULINA d'Orbigny, 1826

Plate 11, fig. 1

Test typically adherent; early chambers in a close coil, later chambers surrounding the periphery in an annular arrangement; chambers in a single layer; test attached by its dorsal side, noninvolute; all chambers usually visible from either dorsal or ventral side; wall perforate, often rather coarsely so; aperture in the early chambers single on the inner border of the chamber in the coiled chambers, in those arranged in an annular manner usually two, one at either end of the chamber and near the preceding chambers adjacent and together forming a series of apertures about the periphery of the test; each newly added chamber connects with the two adjacent chambers at either side in the series next previously formed.

Genus TRUNCATULINA d'Orbigny, 1826

Plate 9, fig. 5

Test free or adherent, rotaliform, the ventral face usually the more convex but passing into species which are nearly biconvex; chambers

usually visible from both sides, occasionally with limbate sutures; wall either smooth or with raised papillæ, occasionally with limbate margins, coarsely punctate; aperture usually a curved slit at the margin of the inner end of the chamber, often with a definite lip.

Genus SIPHONINA Reuss, 1849

Plate 11, fig. 5

Test free, composed of numerous chambers arranged in a somewhat irregular spiral, rounded or biconvex, perforate; wall smooth or ornamented; aperture rounded, usually with a short neck and phialine lip.

Genus ANOMALINA d'Orbigny, 1826

Plate 11, fig. 4

Test nautiloid, composed of numerous chambers, but slightly involute; the two faces usually much alike, biconvex or slightly unsymmetrical; aperture a narrow curved slit at the base of the final chamber.

Genus CARPENTERIA Gray, 1858

Plate 9, fig. 6

Test attached, early chambers rotaliform, later ones becoming irregular and inflated, extending upward in an irregular column; chambers few; wall coarsely perforate; aperture in adult specimens usually with a tubular neck.

Genus RUPERTIA Wallich, 1877

Plate 11, figs. 2, 3

Test attached, columnar; early chambers coiled, later chambers extending up into a coiled column; wall coarsely punctate; aperture a narrow curved slit at the inner margin of the chamber.

Genus PULVINULINA Parker and Jones, 1862

Plate 12, fig. 1

Test usually rotaliform, dorsal side usually convex, ventral side usually flattened; outline typically circular but in some species elongate; wall finely porous, variously ornamented by costæ, bosses, reticulations, or smooth; aperture typically ventral, extending from near the periphery to the umbilicus.

Genus ENDOTHYRA Phillips, 1846

Test calcareous, composed of an outer coarsely perforated layer and inner finely granular, compact layer, chambers numerous, in an irregular spiral coil, aperture of several rounded openings.

Genus ROTALIATINA Cushman, 1925

Test free, trochoid, spiral, composed of about three volutions, the last one composed of numerous chambers, all the chambers exposed from the dorsal side, only those of the last-formed coil visible from the ventral side, umbilicate ventrally; chambers distinct; sutures distinct and usually slightly depressed; wall in the known species smooth; aperture an arched slit between the base of the apertural face and the previous coil.

Genus ROTALIA, Lamarck, 1804

Plate 12, fig. 2

Test free, composed of numerous chambers arranged in a flattened spire, the two sides biconvex or varying from flat above and convex below to convex above and flattened below; all chambers visible from the dorsal side, only those of the last-formed coil visible from below; the umbilical region usually filled with clear shell material; surface variously ornamented with raised bosses or costæ or smooth and unornamented; aperture a single curved opening toward the periphery on the ventral side of the chamber.

Genus CALCARINA d'Orbigny, 1826

Plate 12, fig. 3

Test composed of numerous chambers, close coiled, biconvex; periphery usually with radiating spines; chambers visible at least on the ventral side, sometimes on the dorsal side as well; aperture typically consisting of a row of small openings along the inner margin of the apertural face; supplemental skeleton and canal system highly developed.

Genus SIDEROLITES Lamarck, 1801

Plate 12, fig. 4

Test with early chambers close-coiled, Rotaliform, later with numerous chambers, a few large spines running from the early chambers to the exterior and thence outward; aperture at the base of the last-formed chamber, later in the large perforations of the chamber.

Genus BACULOGYPSINA Sacco (1893) (Tinoporus of Authors)

Plate 12, fig. 5

Test in the very young, rotaliform, later irregular, with numerous small finely punctate chambers, with four to eight or even more sharp tapering spines; supplementary skeleton greatly developed, at the surface, when well preserved, with bosses of clear shell material united with surrounding ones by radial connecting portions of the same sort of material, making a reticulate marking standing out slightly above the surface.

Genus GYPSINA Carter, 1877

Plate 13, fig. 1

Test free or adherent, when free it may be spherical or compressed, when adherent the test takes the form of the object to which it is attached or becomes a raised mass of chambers more or less symmetrical; early chambers forming a flat spire in the higher species, but in most irregularly arranged throughout; wall coarsely porous.

Genus POLYTREMA, Risso, 1826

Test adherent; early chambers small, spirally arranged, soon covered by the irregular loosely growing chambers making an irregular spreading mass, later chambers forming an arborescent growth; wall calcareous, areolated, numerous apertures appearing at the surface on papillæ; interior often of loosely arranged chambers with lacunæ between; color red or pink or sometimes white.

Genus HOMOTREMA Hickson, 1911

The surface is marked by clearly defined areolæ about 0.1 mm. in diameter, perforated by a large number of small foramina, 0.001 mm. in diameter. The boundaries of the areolæ are solid, and there are no pillar pores. Below the surface there may be seen a number of chambers communicating with one another by large open passages and bounded by solid walls. There are no hollow pillars and no foramina except those on the outer walls of the superficial chambers.

Genus SPORADOTREMA Hickson, 1911

The surface of the stem, and, in many cases, of the proximal parts of the branches as well, are not marked by areolæ at all. The foramina are scattered irregularly on the surface and are of relatively large size. There are no pillar pores. Below the surface there may be seen a number of chambers communicating with one another by

large open passages and bounded by solid walls. There are no hollow pillars and no foramina except those on the outer walls of the superficial chambers.

Family 9. NUMMULITIDAE

Test calcareous, perforate, the chambers usually numerous, arranged in a spiral, either umbilicate or completely involute, surface variously ornamented ; chamber walls in the higher forms with secondary canal system.

Subfamily 1. FUSULININAE

Test fusiform or subglobular, chambers extending from pole to pole, each convolution completely covering the preceding whorls, wall finely perforate ; aperture an elongated slit or series of pores at the base of the last-formed chamber.

Genus SCHWAGERINA Möller, 1887

Test subspherical, chambers divided into chamberlets by simple, straight, secondary septæ ; aperture a single opening or series of pores.

Genus FUSULINA Fischer, 1829

Test fusiform or subglobular ; chambers not completely subdivided ; aperture simple.

Subfamily 2. POLYSTOMELLINAE

Test bilaterally symmetrical ; nautiloid, higher forms with a supplemental skeleton and secondary canal system.

Genus NONIONINA d'Orbigny, 1826

Plate 13, fig. 2

Test composed of numerous chambers arranged to form a bilateral, planospiral coil, the last formed volution usually embracing all the preceding ones ; walls usually smooth, sometimes pitted, very finely perforated ; aperture a narrow opening or row of openings at the base of the apertural face between it and the preceding volution.

Genus POLYSTOMELLA Lamarck, 1822

Plate 13, fig. 3

Test composed of numerous chambers, arranged in a regular, bilaterally symmetrical, involute spire, the chambers extending back

to the umbilical region so that only the last formed whorl is visible, chambers either inflated with depressed sutures bridged across at regular intervals or the sutures may be limbate and the processes form a regular series of elevated ridges connecting the sutures; aperture either a simple opening at the base of the apertural face of the chamber or subdivided into a series of openings.

Genus ARCHAEDISCUS H. B. Brady, 1873

Test lenticular, unsymmetrical, spirally coiled; segments irregularly constricted and expanded to form chambers; canal system and supplementary skeleton wanting.

Genus AMPHISTEGINA d'Orbigny, 1826

Plate 13, fig. 4

Test spiral, lenticular, more convex on one side than the other, the last-formed volution usually covering the others, chambers with the alar projections on one side simple, divided on the other side by deep constrictions to form supplementary lobes; wall thickened near the umbilicus, usually smooth except near the aperture on the ventral side where it is usually papillose, no true secondary canal system developed; aperture on the ventral side at the base of the chamber, simple.

Genus OPERCULINA d'Orbigny, 1826

Plate 13, fig. 5

Test coiled, compressed, consisting of numerous chambers in three or four volutions, bilaterally symmetrical, and all visible from either side, not embracing, except in the early whorls, in face view very thin, usually thickest at the umbonal region; surface smooth or ornamented with bosses; aperture single at the base of the apertural wall of the chamber.

Genus HETEROSTEGINA d' Orbigny, 1826

Plate 13, fig. 6

Test compressed, especially the last-formed whorl, the early whorls often embracing and fairly thick, lenticular in side view; chambers numerous, subdivided into chamberlets by transverse partitions and visible from the exterior; secondary canal system developed and comparable to *Operculina;* aperture consisting of a row of pores on the outer face of the chamber, one pore for each of the chamberlets.

Genus **NUMMULITES** Lamarck, 1801

Test coiled, biconvex, usually bilaterally symmetrical, composed of numerous volutions. The chambers numerous and extending to the umbo, each volution completely inclosing the preceding ones, the periphery often keeled, aperture a simple V-shaped opening at the base of the apertural face of the chamber.

Genus **OPERCULINELLA** Yabe, 1918

Test in early development lenticular and close coiled, later developing an alar projection, supplementary skeleton and canal system well developed.

Subfamily 4.   CYCLOCLYPEINAE

Test flat with a thickened center, or lens-shaped, with two sets of chambers, equatorial, forming a central plane of the test and lateral, piled in columns at either side ; test strengthened by solid pillars extending from the equatorial band to the surface ; septæ double with internal canals.

Genus **ORBITOIDES** d'Orbigny, 1847

Test discoidal, equatorial chambers diamond-shaped.

Genus **ORTHOPHRAGMINA** Munier-Chalmas

Plate 16, fig. 6

Test discoidal or stellate, equatorial chambers rectangular.

Genus **LEPIDOCYCLINA** Gümbel, 1868

Plate 16, figs. 4, 5

Test discoidal, equatorial chambers typically hexagonal.

Genus **MIOGYPSINA** Sacco 1893

Test irregularly discoidal, equatorial chambers rounded.

Genus **CYCLOCLYPEUS** Carpenter, 1856

Test thin, compressed, discoidal, usually of a single layer of chambers, centrally thickened, chambers rectangular.

Family 10. MILIOLIDAE

Test typically calcareous, imperforate except in the very early stages of certain genera, porcellanous; sometimes the exterior with arenaceous covering, but always on an imperforate calcareous base, aperture typically with a tooth variously modified in different genera.

Subfamily 1. CORNUSPIRININAE

Test usually free, the early stages composed of a proloculum and elongate, coiled second chamber, later chambers typically planospiral, of various lengths in typical chambers of the included genera.

Genus CORNUSPIRA Schultze, 1854

Plate 12, fig. 6

Test consisting of a proloculum followed by a long coiled tubular chamber, typically without septæ, complanate, the open end serving as the aperture, occasionally somewhat constricted or with a thickened lip, wall porcellanous.

Genus OPTHALMIDIUM Zwingli and Kübler, 1870

Plate 14, fig. 1

Test in general planospiral, compressed, all chambers visible from the exterior on both sides, proloculum globular, followed by a coiled second chamber making usually two or more coils, the following chambers gradually decreasing in relative length, more or less loose coiled, the intermediate area filled in with a shelly plate; aperture at the end of the chamber, rounded, without lip or teeth.

Genus SPIROLOCULINA d'Orbigny, 1826

Plate 14, fig. 2

Test composed of chambers arranged planospirally, all visible typically from opposite sides of the test, early chambers after the proloculum sometimes a coil or more in length, but the adult chambers one-half coil in length; aperture typically somewhat produced; aperture circular, with a prominent lip and a bifid tooth occasionally, with a secondary tooth directly opposite the primary one.

Genus PLANISPIRINA Seguenza, 1880

Test planospiral, chambers in the later growth often more or less involute, concealing the early development, which consists of an oval

proloculum, followed by the typical *Cornuspira*-like second chamber, in turn followed by several chambers gradually becoming shorter, those of the adult being less than a half coil in length, usually three or four necessary to make a complete coil.

Genus Vertebralina d'Orbigny, 1826

Plate 14, fig. 3

Test with the early chambers planospiral, at least from external appearances, later ones becoming rectilinear ; wall porcellanous, imperforate, usually ornamented by striations or costæ ; aperture a long narrow slit either at the outer end of the chamber or somewhat laterally placed ; typically with a definite lip.

Genus NODOBACULARIA Rhumbler, 1895

Plate 14, fig. 4

Test composed of a proloculum and second *Cornuspira*-like chamber, usually directly followed by a linear series of subcylindrical chambers ; test imperforate, calcareous.

Genus NUBECULARIA Defrance, 1825

Plate 14, fig. 5

Test typically coiled, planospiral, free or attached, consisting of an oval proloculum and second *Cornuspira*-like chamber of variable length, followed by several chambers irregular in shape and arrangement, but usually more or less distinctly planospiral, apertures one or more, irregularly arranged, wall smooth, roughened, or with incorporated sand grains.

Subfamily 2. QUINQUELOCULININAE

Test in the adult or in the early development of the test, at least in the microspheric form with the chambers a half coil in length and added in planes 144° from one another, five planes being necessary to complete a cycle before a new chamber is added directly above one of the previous ones, aperture at this stage at least alternately at opposite poles of the test.

Genus QUINQUELOCULINA d'Orbigny, 1826

Plate 14, fig. 6

Test in the young with the usually oval proloculum and short, *Cornuspira*-like second chamber, followed by the adult character both

in the microspheric and megalospheric forms of the species. This adult character consists of chambers a half coil in length added successively in planes 144° apart, five chambers being thus added before a cycle is completed and a new chamber added in the plane of the fifth preceding chamber and covering it exteriorly. The chambers are thus 72° from one another, but each as added is 144° from its immediately preceding one in the series; aperture typically elongate with a simple tooth and with little or no elongation of the neck except in certain of the more complex species.

Genus MASSILINA Schlumberger, 1893

Plate 14, fig. 7

Test composed of a globular proloculum followed by a *Cornuspira*-like chamber, making a half coil, these in turn followed by a series of quinqueloculine chambers, in the adult composed of chambers arranged like *Spiroloculina* in a single plane, leaving the center open and the chambers a half coil in length.

Genus ARTICULINA d'Orbigny, 1826

Plate 14, fig. 8

Early chambers usually quinqueloculine or triloculine, later ones in a uniserial arrangement, varying considerably in number according to the species; aperture in the adult a rounded, usually elliptical opening, in a depression with a definite phialine lip.

Genus SIGMOILINA Schlumberger, 1887

Plate 14, fig. 9

Test in its early stages quinqueloculine, later developing chambers a half coil in length in two series, with each newly added chamber in a plane more than 180° from the previous one, so that the horizontal plane in section shows a gradual turning about the elongate axis of the test, aperture typically with a single, simple tooth.

Genus HAUERINA d'Orbigny, 1848

Plate 15, fig. 1

Test compressed with the early chambers milioline, the later and greater portion of the test having the chambers arranged in a plano-spiral manner, usually in the last-formed coil at least with more than two chambers in each whorl, surface smooth or ornamented; aperture of a large number of small pores forming a sieve-like plate, usually much longer than wide.

Genus TRILOCULINA d'Orbigny, 1826

Plate 15, fig. 2

Test in its adult development consisting, as seen from the exterior, of three visible chambers added in planes 120° from one another, the third of each series added in the plane of the third preceding and covering it.

Genus ADELOSINA d'Orbigny, 1826

Test in its early portion consisting of a large, laterally compressed proloculum, followed by a second chamber making a complete coil and covering the exterior of the proloculum, later chambers making a half coil, variously ornamented, most frequently with longitudinal costæ.

Genus BILOCULINA d'Orbigny, 1826

Plate 15, fig. 3

Test in the adult, composed of chambers one-half coil in length, in planes 180° from one another, only the two chambers last formed visible from the exterior; aperture usually broader than long, typically with a bifid tooth.

Genus FABULARIA Defrance, 1820

Like Biloculina but the chambers with secondary divisions, aperture cribrate.

Genus NEVILLINA Sidebottom, 1905

Plate 15, figs. 4, 5

Test free, elongate, more or less pyriform, circular in transverse section, the final single chamber completely embracing the previous one; aperture circular, complex, formed by numerous incurved lamellæ, meeting centrally.

Genus IDALINA Schlumberger and Munier-Chalmas, 1884

Test subglobular, early stages as in Biloculina, final chamber covers all previous ones; aperture cribrate.

Genus PENEROPLIS Montfort, 1808

Plate 15, fig. 6

Test planospiral, at least in the early stages, whole test lenticular, thick or much compressed, circular, crosier-shaped or cylindrical; surface smooth or the chambers longitudinally striate; chambers entire, not subdivided as in the following genera; aperture in the

complanate forms consisting of a linear series of pores on the apertural face, in the less compressed forms an irregularly arranged series of pores and in the more or less uncoiled forms often becoming dendritic.

Genus ORBICULINA Lamarck, 1816

Plate 16, figs. 2, 3

Test planospiral, at least in its early stages, the chambers numerous, and in the later stages, at least, subdivided into chamberlets, the early chambers in all forms extending over the early test to the umbilical region, making a completely involute test in the early stages, later chambers may continue the completely involute character, or may become annuli or build a crosier-shaped test, wall usually pitted, sometimes smooth ; aperture in the adult usually consisting of a double row of small circular openings usually opposite, along the median portion of the apertural face of the test.

Genus ORBITOLITES Lamarck, 1801

Plate 16, fig. 1

Test typically discoidal, the early chambers, in the microspheric form at least, following the proloculum and *Cornuspira*-like second chamber, arranged in a gradually widening spiral, followed by chambers extending in length and becoming annuli ; chambers divided into chamberlets, each with one or more apertures on the rim of the test.

Genus CRATERITES Heron-Allen and Earland, 1924

Test apparently sessile or becoming free, with a basal layer of a nubecularine mass of chambers without spiral arrangement, arising from which is a thick trunk, nearly circular in section, composed of superimposed rings of chamberlets, orbitoline in appearance but without marginal pores ; test widest near the top, the upper surface with a thin, highly convex apertural surface, entirely covered with close perforations forming the apertures.

Genus ALVEOLINA d'Orbigny, 1826

Plate 15, figs. 7, 8

Test usually elliptical or fusiform, composed in the adult of elongate chambers, each running the entire length of the test, the apertural face of the last-formed chamber forming the growing edge of the test ; chambers divided into chamberlets with small circular apertures upon the apertural face, at least in the larger species ; whole test spirally coiled about the elongate axis.

Genus KERAMMOSPHAERA H. B. Brady

Test spherical, chambers more or less irregularly arranged in concentric layers.

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EXPLANATION OF PLATES

PLATE 1

Fig. 1. *Astrorhiza granulosa* (H. B. Brady.) × 13.
2. *Rhabdammina abyssorum* W. B. Carpenter. × 13.
3. *Marsipella gigantea* Cushman. × 7.
4. *Bathysiphon flavidus* de Folin, var. *giganteus* Cushman. × 3. *a*, side view; *b*, end view.
5. *Rhizammina indivisa* H. B. Brady. × 27.
6. *Psammosphaera parva* Flint. × 66.
7. *Sorosphaera confusa* H. B. Brady. × 15. (After Brady.)
8. *Storthosphaera albida* F. E. Schulze. × 20. (After Brady.)
9. *Saccammina sphaerica* G. O. Sars. × 15. (After Brady.)
10. *Proteonina diffugiformis* (H. B. Brady). × 50. (After Rhumbler.)
11. *Pelosina rotundata* H. B. Brady. × 20. (After Brady.)
12. *Hippocrepina indivisa* Parker. × 45. (After Brady.)
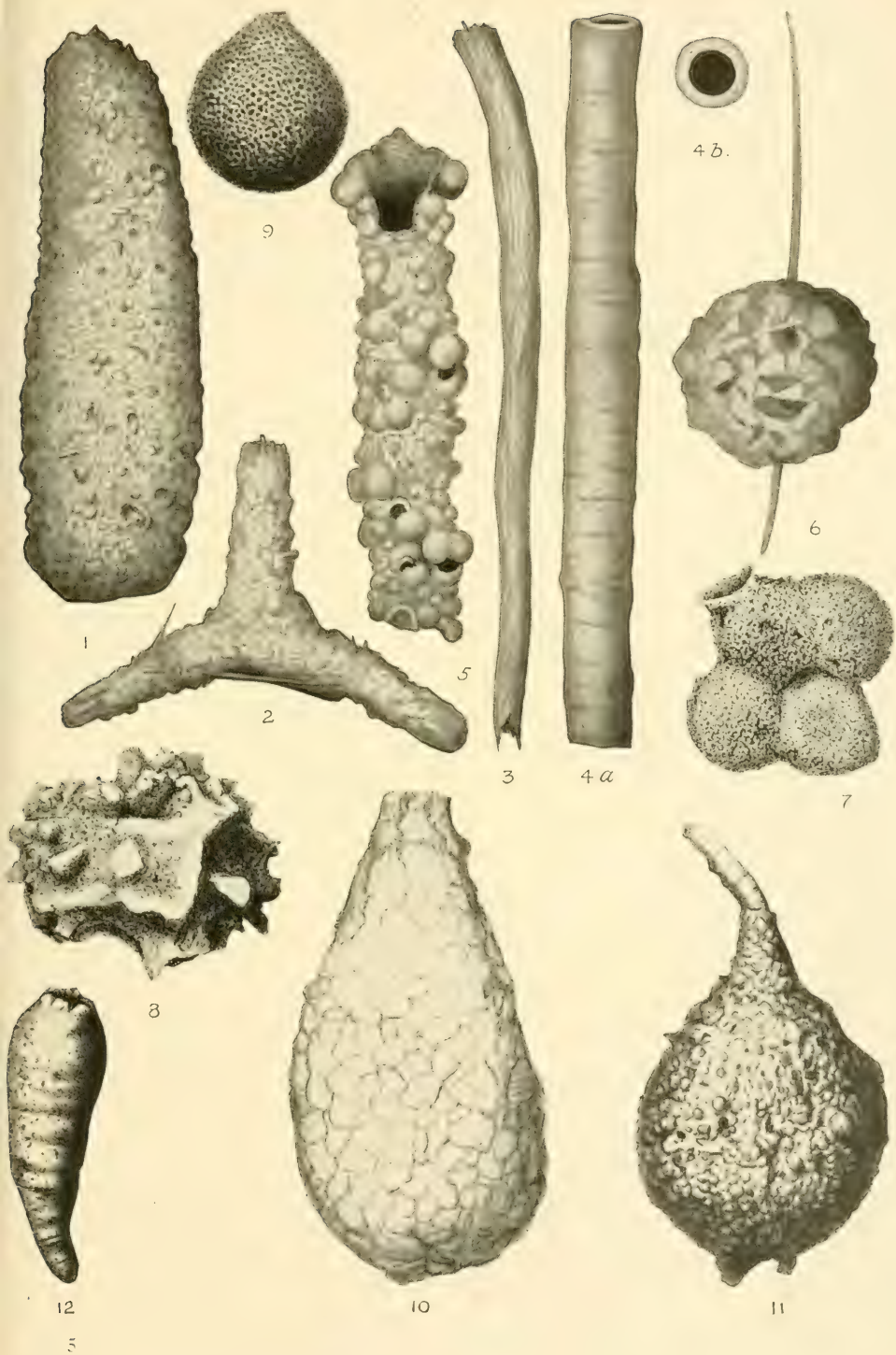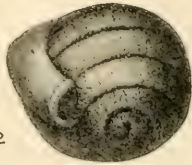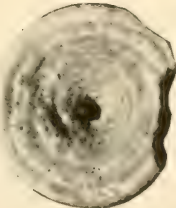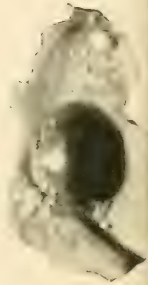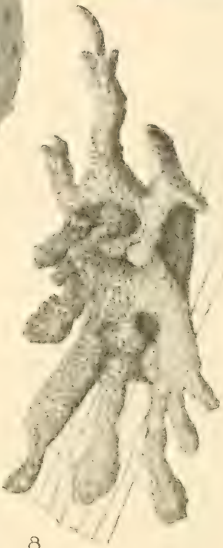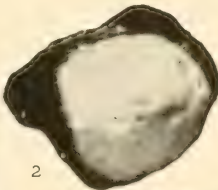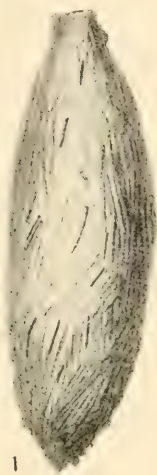
PLATE 2

Fig. 1. *Technitella legumen* Norman. $\times$ 50. (After Brady.)
　　2. *Webbinella hemisphaerica* (Jones, Parker, and H. B. Brady). $\times$ 15.
　　　　Specimen attached to black pebble.
　　3. *Tholosina bulla* (H. B. Brady). $\times$ 33.
　　4. *Thurammina papyracea* Cushman. $\times$ 33.
　　5. *Hyperammina subnodosa* H. B. Brady. $\times$ 15.
　　6. *Saccorhiza ramosa* (H. B. Brady). $\times$ 30.
　　7. *Jaculella acuta* H. B. Brady. $\times$ 12.
　　8. *Dendrophrya radiata* Str. Wright. $\times$ 45. (After Brady.)
　　9. *Haliphysema tumanowiczii* Bowerbank. $\times$ 20. Group of attached
　　　　specimens. (After Brady.)
　　10. *Ammolagena clavata* (Parker and Jones). $\times$ 30.
　　11. *Ammodiscoides turbinatus* Cushman. $\times$ 15.
　　12. *Glomospira charoides* (Jones and Parker). $\times$ 70. (After Brady.)

PLATE 3

FIG. 1. *Tolypammina vagans* (H. B. Brady). × 30.

2. *Ammodiscus incertus* (d'Orbigny). × 10. Megalospheric form.

3. *Aschemonella catenata* (Norman). × 15. (After Brady.)

4. *Reophax nodulosus* H. B. Brady. × 15.

5. *Hormosina ovicula* H. B. Brady. × 15.

6. *Haplostiche dubia* (d'Orbigny). × 7. *a*, side view; *b*, apertural view.

7. *Trochamminoides proteus* (Karrer). × 20.

8. *Haplophragmoides subglobosum* (G. O. Sars). × 25. *a*, apertural view; *b*, side view.

9. *Cyclammina pauciloculata* Cushman. × 18. *a*, side view; *b*, apertural view.

10, 11. *Ammochilostoma galeata* (H. B. Brady). × 50. (After Brady.) 10, side view; 11, apertural view.
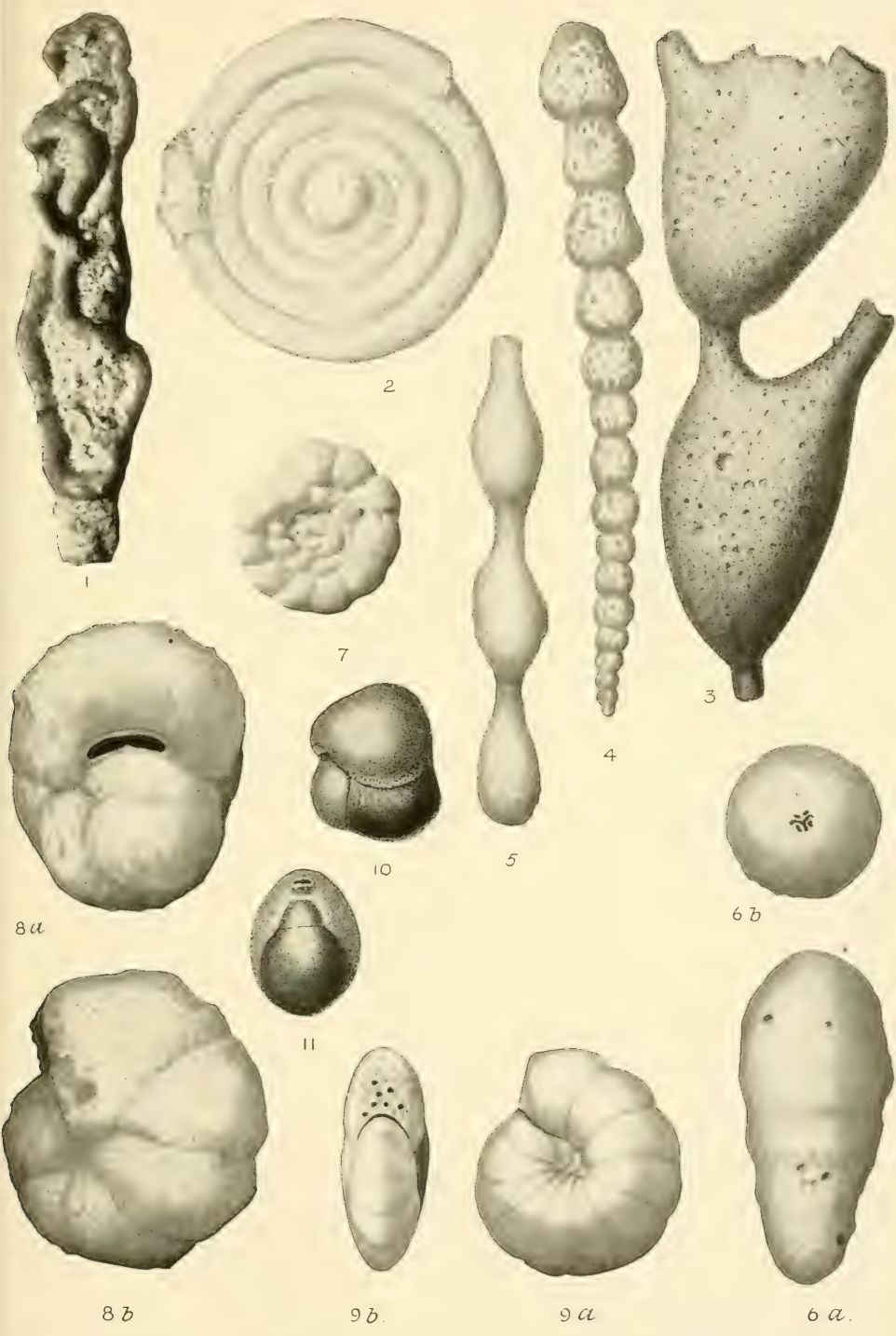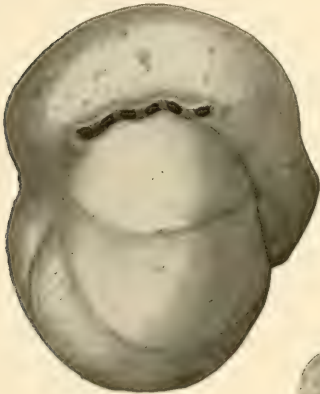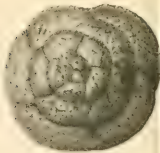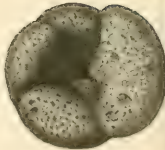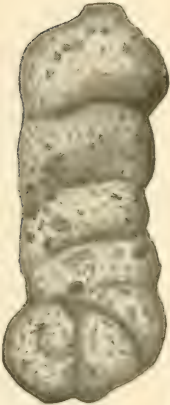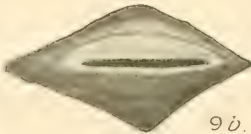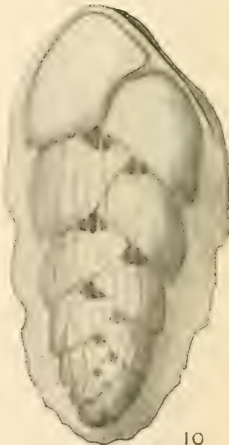
PLATE 4

Fig. 1. *Cribrostomoides bradyi* Cushman. × 25. *a*, side view ; *b*, apertural view.
  2. *Lituotuba lituiformis* (H. B. Brady). × 20.
  3. *Ammobaculites calcareum* (H. B. Brady). × 18.
  4. *Lituola mexicana* Cushman. × 15.
  5. *Trochammina globulosa* Cushman. × 20. *a*, dorsal view ; *b*, ventral view.
  6. *Globotextularia anceps* (H. B. Brady). × 20. (After Brady.)
  7. *Ammosphaeroidina grandis* Cushman. × 15.
  8. *Spiroplecta bulbosa* Cushman. × 85.
  9. *Bigenerina capreolus* (d'Orbigny). × 25. *a*, front view ; *b*, apertural view.
  10. *Bolivina hantkeniana* H. B. Brady. × 35.

PLATE 5

FIG. 1. *Textularia rugosa* (Reuss). $\times$ 35. *a*, front view; *b*, apertural view.
2. *Pleurostomella subnodosa* (Reuss). $\times$ 75. *a*, front view; *b*, side view.
3. *Pavonina flabelliformis* (d'Orbigny). $\times$ 75. Front view.
4. *Verneuilina bradyi* Cushman. $\times$ 75.
5. *Valvulina fusca* (Williamson). $\times$ 60. *a*, dorsal view; *b*, ventral view.
6. *Tritaxia tricarinata* (Reuss). $\times$ 25. *a*, front view; *b*, apertural view.
7. *Chrysalidina dimorpha* H. B. Brady. $\times$ 70. Front view. (After Brady.)
8. *Bulimina pupoides* d'Orbigny. $\times$ 75.
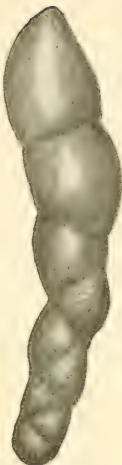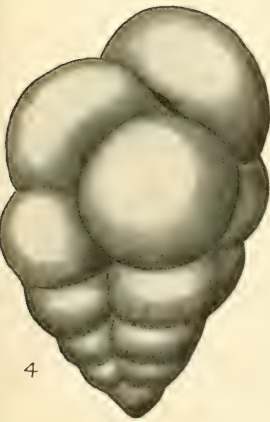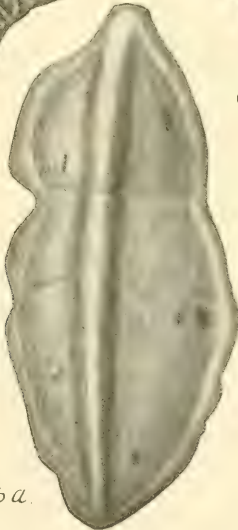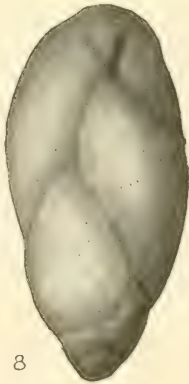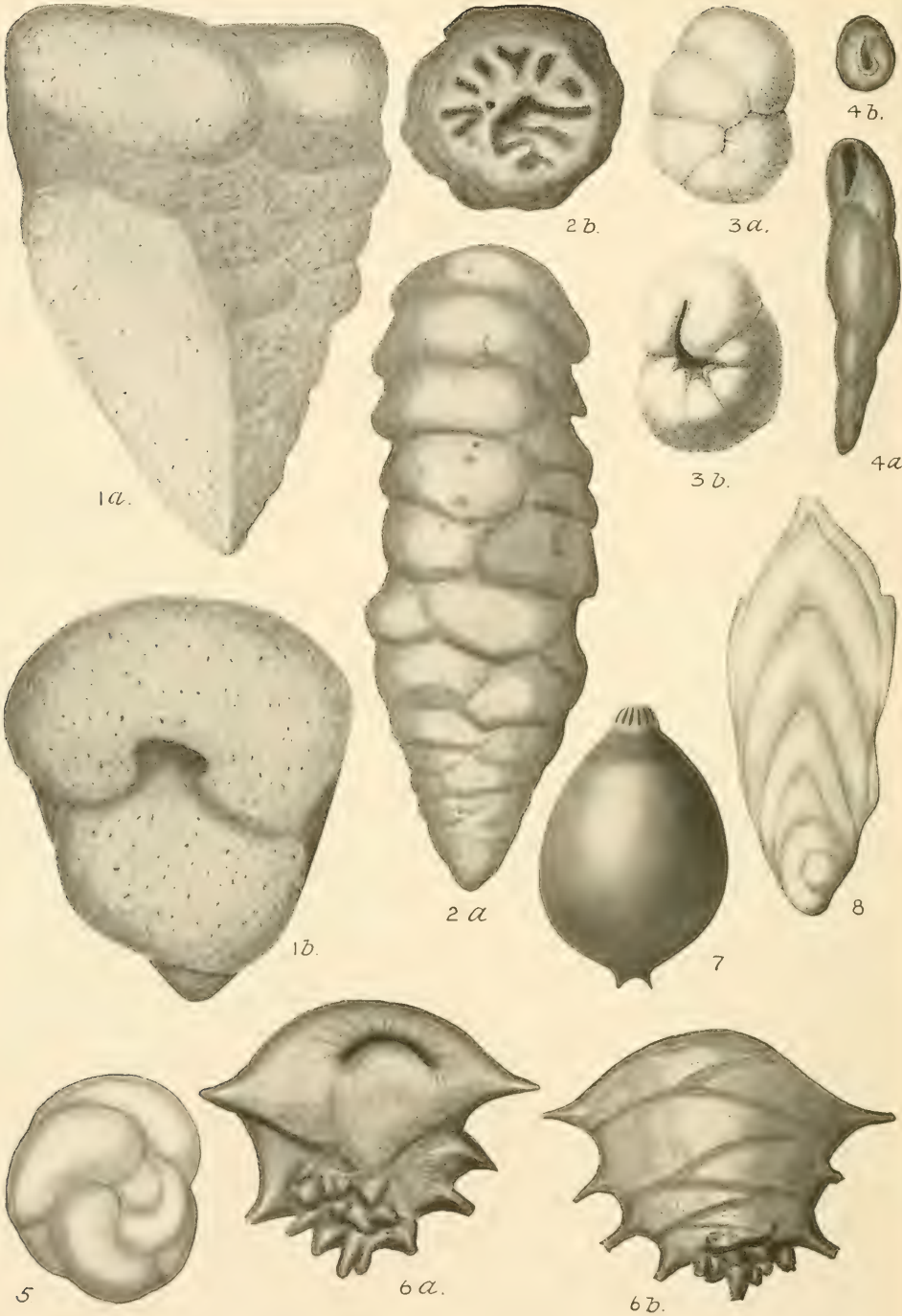
PLATE 6

FIG. 1. *Gaudryina robusta* Cushman. $\times$ 18. *a*, ventral view; *b*, apertural view.
    2. *Tritaxilina caperata* (H. B. Brady). $\times$ 25. *a*, front view; *b*, apertural view.
    3. *Buliminella contraria* (Reuss). $\times$ 60. *a*, dorsal view; *b*, ventral view. (After Brady.)
    4. *Virgulina schreibersiana* Czjzek. $\times$ 60. *a*, apertural view; *b*, front view.
    5. *Cassidulina laevigata* d'Orbigny. $\times$ 75.
    6. *Ehrenbergina hystrix* H. B. Brady. $\times$ 40. *a*, ventral view; *b*, dorsal view.
    7. *Lagena apiculata* (Reuss). $\times$ 33.
    8. *Frondicularia inaequalis* Costa. $\times$ 66.

PLATE 7

Fig. 1. *Clavulina difformis* (H. B. Brady). × 50. *a*, front view; *b*, apertural
        view.
     2. *Buliminoides williamsoniana* (H. B. Brady). × 60. *a*, apertural view;
        b, front view.
     3. *Nodosaria raphanus* (Linnaeus). × 16. *a*, apertural view; *b*, front
        view.
     4. *Lingulina grandis* Cushman. *a*, front view, × 12; *b*, apertural view,
        × 16.
     5. *Trifarina bradyi* Cushman. × 80. *a*, *b*, side view; *c*, apertural view.
     6. *Marginulina striatula* Cushman. × 66.
     7. *Allomorphina trigona* Reuss. × 60. (After Brady.) *a*, ventral view;
        b, dorsal view.
     8. *Polymorphina lactea* (Walker and Jacob), var. *oblonga* Williamson.
        × 66.
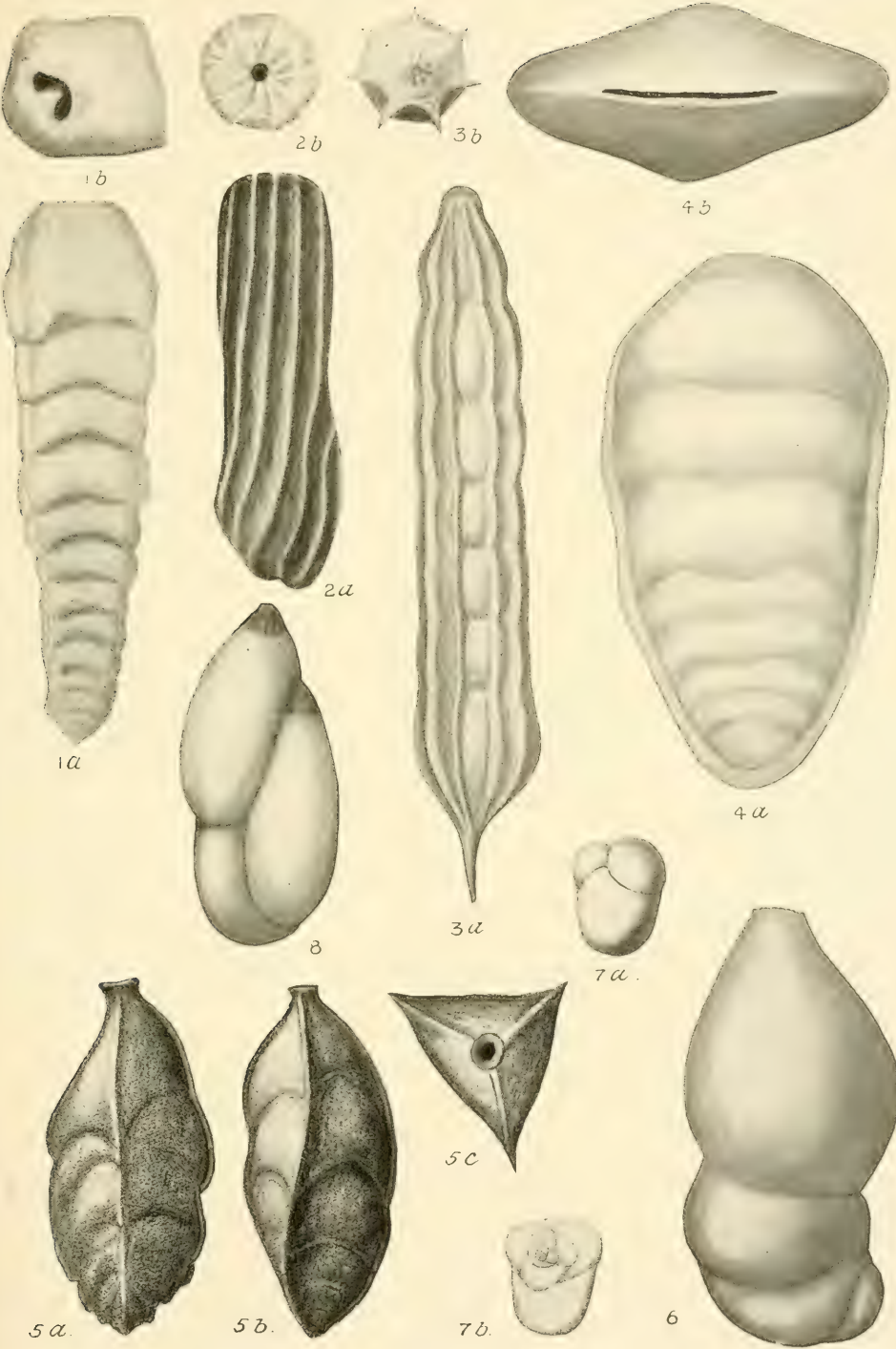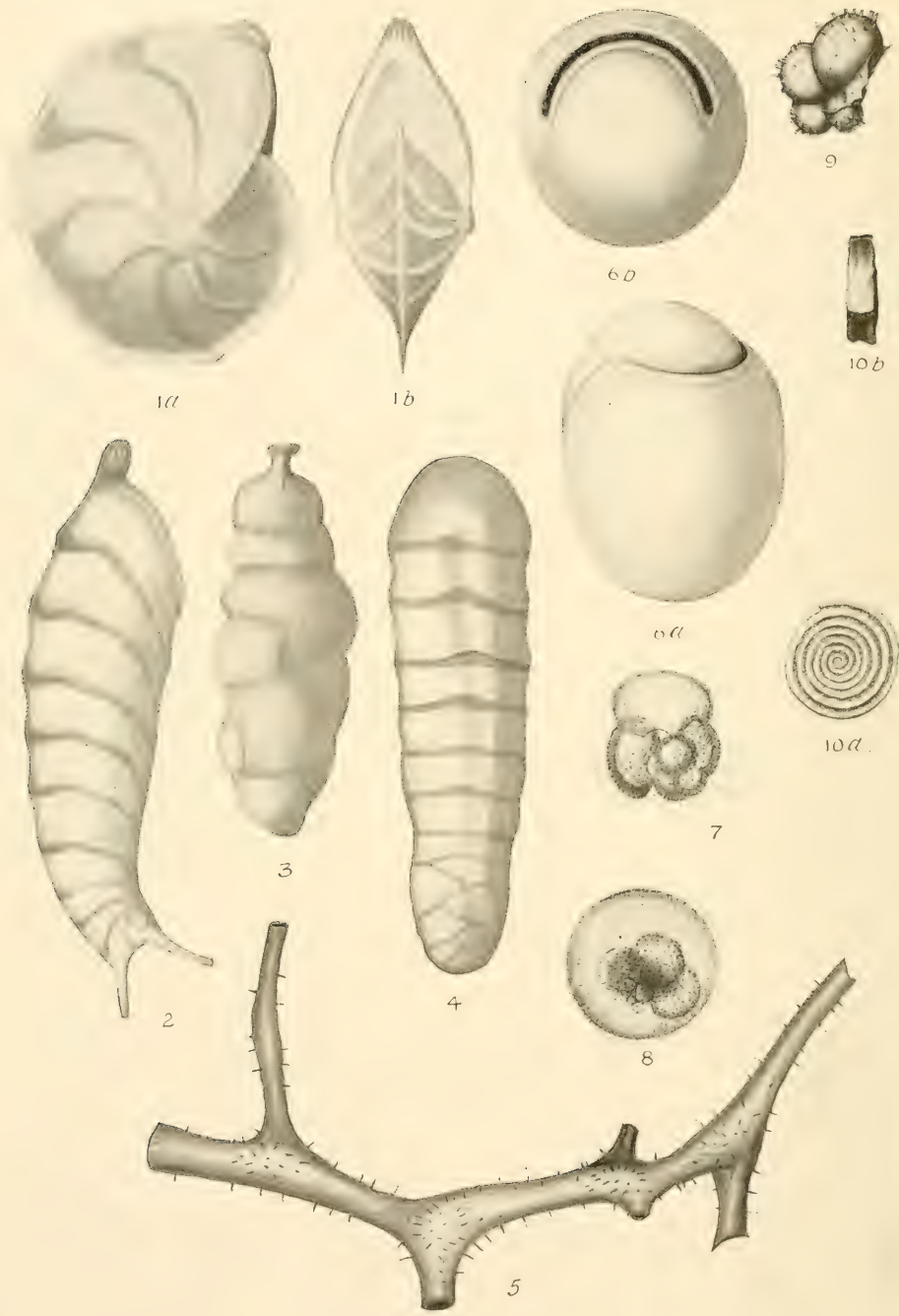
PLATE 8

FIG. 1. *Cristellaria calcar* (Linnaeus). × 33. *a*, side view; *b*, edge view.
2. *Vaginulina spinigera* H. B. Brady. × 33.
3. *Uvigerina tenuistriata* Reuss. × 66.
4. *Siphogenerina bifrons* (H. B. Brady). × 66.
5. *Ramulina globulifera* H. B. Brady. × 33.
6. *Chilostomella grandis* Cushman. × 20. *a*, side view; *b*, apertural view.
7. *Globigerina conglobata* H. B. Brady. × 50. (After Brady.)
8. *Orbulina universa* d'Orbigny. × 50. (After Brady.) Specimen viewed by transmitted light showing *Globigerina*-like young within.
9. *Hastigerina pelagica* d'Orbigny. × 38. (After Brady.)
10. *Spirillina limbata* H. B. Brady. × 60. *a*, side view; *b*, peripheral view. (After Brady.)

PLATE 9

FIG. 1.   *Candeina nitida* d'Orbigny. $\times$ 75.   *a*, side view; *b*, ventral view.

2.   *Sphaeroidina dehiscens* Parker and Jones. $\times$ 55.

3.   *Pullenia sphaeroides* (d'Orbigny). $\times$ 75.   *a*, side view; *b*, apertural view.

4.   *Patellina corrugata* Williamson. $\times$ 120.   *a*, dorsal view; *b*, ventral view.   (After Brady.)

5.   *Truncatulina culter* (Parker and Jones). $\times$ 66.   *a*, ventral view; *b*, dorsal view; *c*, apertural view.

6.   *Carpenteria proteiformis* Goës. $\times$ 15.

1 a.

1 b.

3 a

4 a

3 b

2
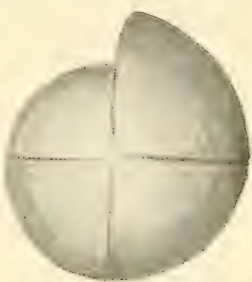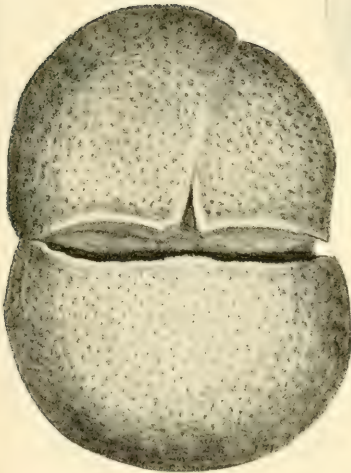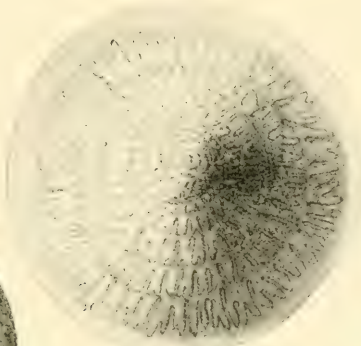
+ b.

6

5 a.

5 c.
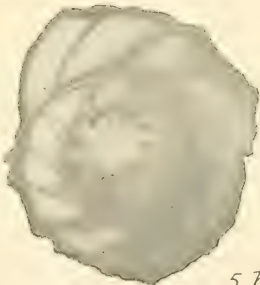
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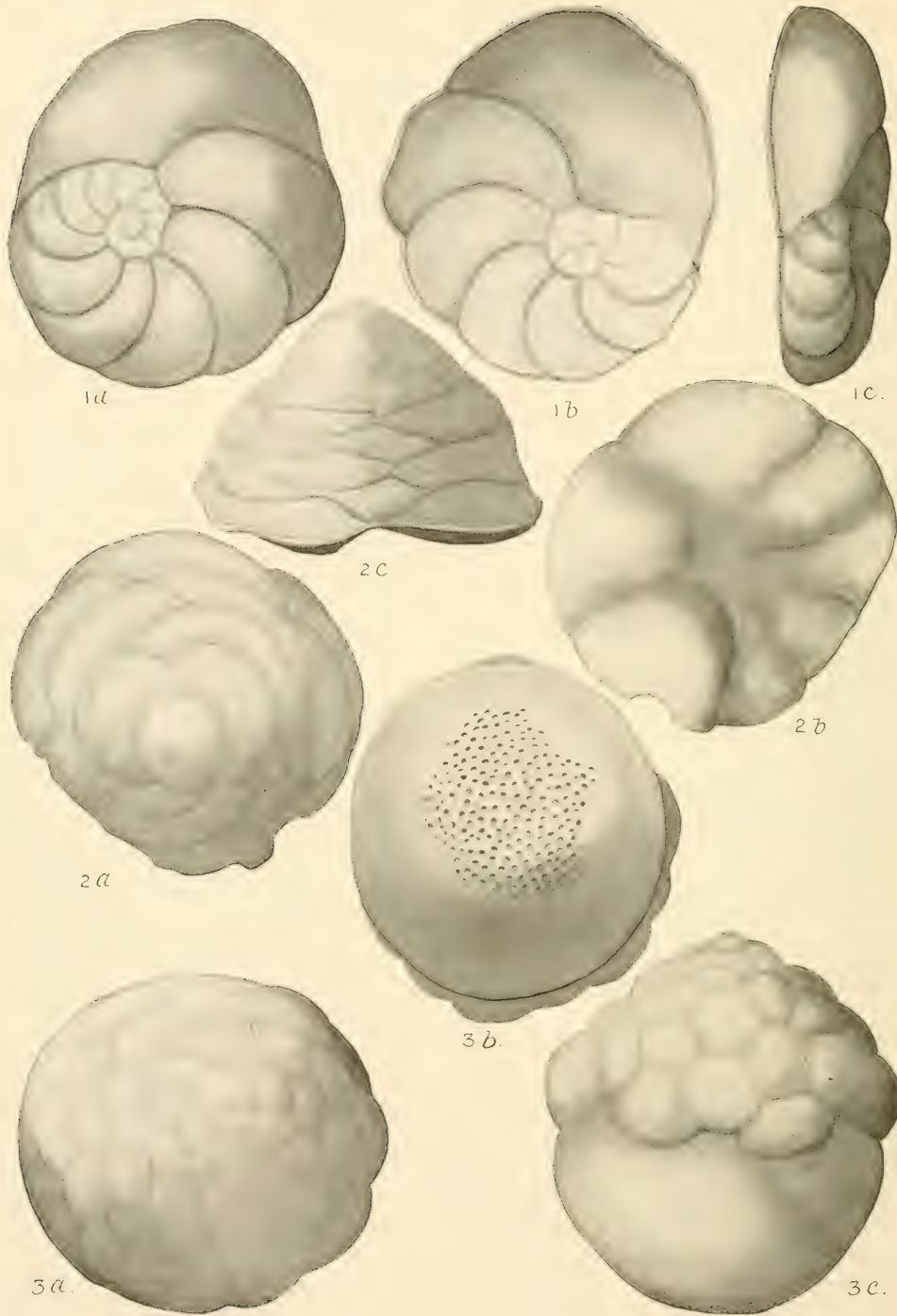
PLATE 10

FIG. 1. *Discorbis bertheloti* (d'Orbigny). $\times$ 25. *a*, dorsal view; *b*, ventral view; *c*, side view.

    2. *Cymbalopora poeyi* (d'Orbigny). $\times$ 50. *a*, dorsal view; *b*, ventral view; *c*, side view.

    3. *Tretomphalus bulloides* (d'Orbigny). $\times$ 50. *a*, dorsal view; *b*, ventral view; *c*, side view.

6

PLATE 11

Fig. 1. *Planorbulina mediterranensis* (d'Orbigny). $\times 75$. *a*, dorsal view; *b*, peripheral view.

2. *Rupertia stabilis* Wallich. $\times 40$. (After Brady.)

3. *Rupertia stabilis* Wallich. $\times 40$. (After Brady.) Section.

4. *Anomalina ammonoides* (Reuss). $\times 66$. *a*, ventral view; *b*, dorsal view; *c*, apertural view.

5. *Siphonina reticulata* (Czjzek). $\times 70$. *a*, dorsal view; *b*, ventral view; *c*, side view.
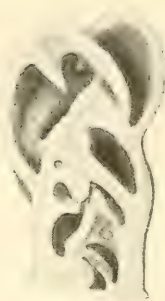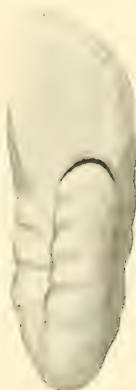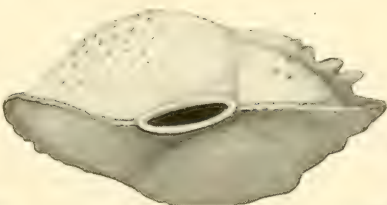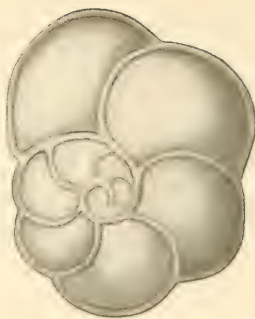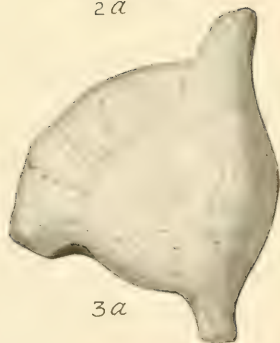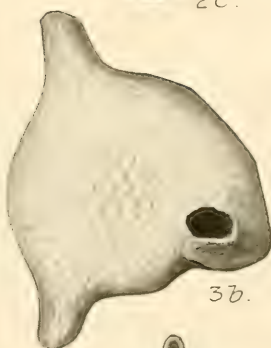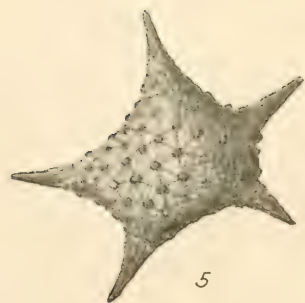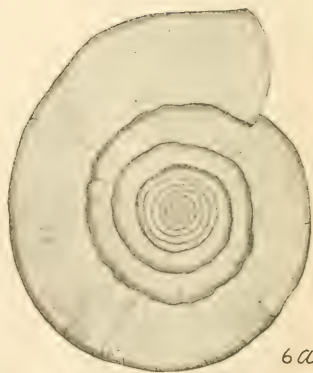
PLATE 12

FIG. 1. *Pulvinulina menardii* (d'Orbigny). $\times$ 33. *a*, ventral view; *b*, dorsal view; *c*, apertural view.
  2. *Rotalia beccarii* (Linnaeus). $\times$ 66. *a*, ventral view; *b*, dorsal view; *c*, apertural view.
  3. *Calcarina spengleri* (Gmelin). $\times$ 30. *a*, dorsal view; *b*, ventral view.
  4. *Siderolites tetraedra* (Gümbel). $\times$ 15.
  5. *Baculogypsina sphaerulatus* (Parker and Jones). $\times$ 20.
  6. *Cornuspira foliacea* (Philippi). $\times$ 20. *a*, front view; *b*, apertural view.

PLATE 13

Fig. 1. *Gypsina inhaerens* (Schultze). $\times$ 30. (After Brady.)
2. *Nonionina umbilicatula* (Montagu). $\times$ 75. *a*, side view; *b*, face view.
3. *Polystomella macella* (Fichtel and Moll). $\times$ 66. *a*, side view; *b*, face view.
4. *Amphistegina lessonii* d'Orbigny. $\times$ 30.
5. *Operculina bartschi* Cushman, var. *ornata* Cushman. $\times$ 10. *a*, side view; *b*, apertural view.
6. *Heterostegina depressa* d'Orbigny, young specimen. $\times$ 35.
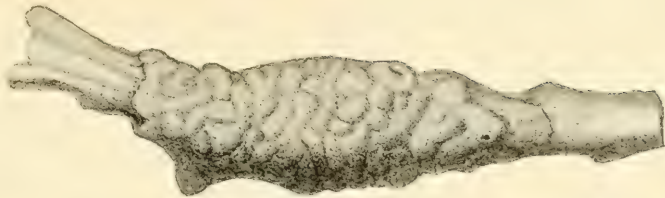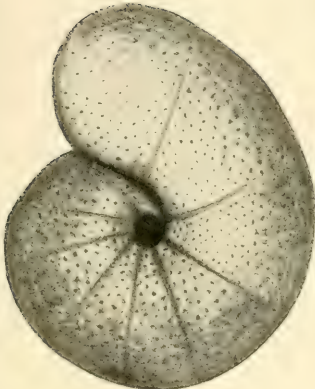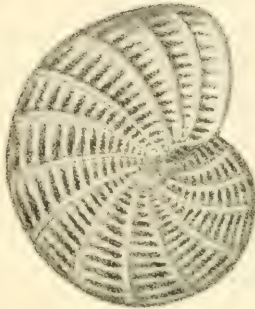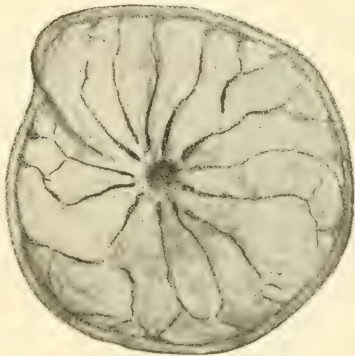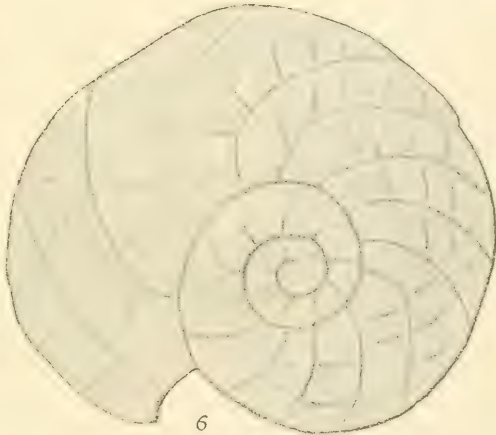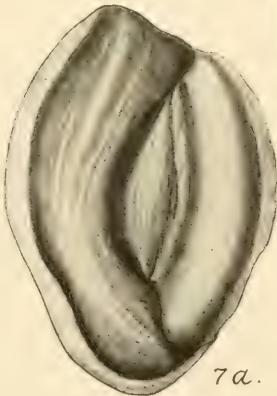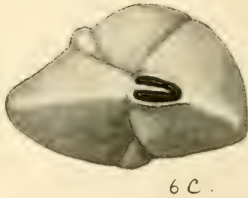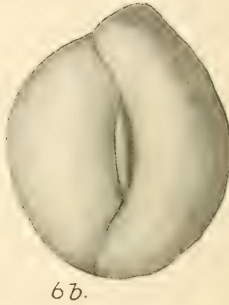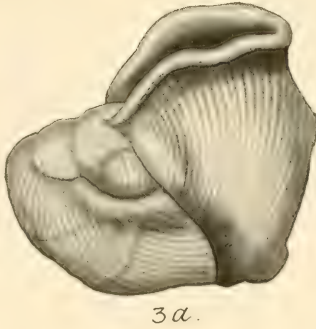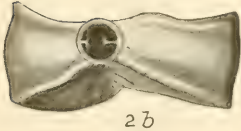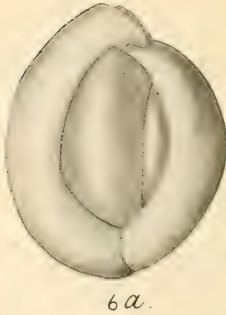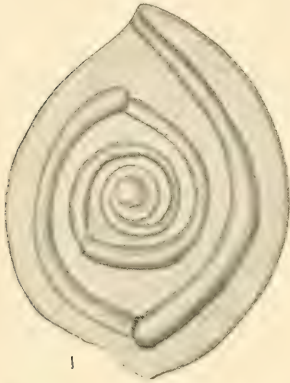
PLATE 14

Fig. 1. *Opthalmidium inconstans* (H. B. Brady.) ✕ 65.

2. *Spiroloculina grateloupi* d'Orbigny. ✕ 35. *a,* front view; *b,* apertural view.

3. *Vertebralina striata* d'Orbigny. ✕ 65. *a,* front view; *b,* apertural view.

4. *Nodobacularia tibia* Jones and Parker. ✕ 130. Showing proloculum, second *Cornuspira*-like chamber and the first of the uniserial chambers. (After Rhumbler.)

5. *Nubecularia bradyi* Millett. ✕ 190. (After Rhumbler.)

6. *Quinqueloculina vulgaris* d'Orbigny. ✕ 23. *a,* side view; *b,* opposite view; *c,* apertural view.

7. *Massilina durrandii* Millett. ✕ 20. *a, b,* opposite sides; *c,* apertural view.

8. *Articulina sagra* d'Orbigny. ✕ 35. (After Brady.)

9. *Sigmoilina sigmoidea* (H. B. Brady), section. ✕ 40. (After Brady.)

PLATE 15

FIG. 1. *Hauerina ornatissima* (Karrer). $\times$ 65. *a*, front view; *b*, apertural view.
  2. *Triloculina oblonga* (Montagu). $\times$ 39. *a*, side view; *b*, opposite side; *c*, apertural view.
  3. *Biloculina anomala* Schlumberger. $\times$ 50. *a*, front view; *b*, side view; *c*, apertural view.
  4. *Nevillina coronata* (Millett). $\times$ 25. Showing penultimate chamber within.
  5. *Nevillina coronata* (Millett). $\times$ 25. *a*, front view; *b*, apertural view.
  6. *Peneroplis pertusus* (Forskål), var. *planatus* (Fichtel and Moll). $\times$ 65. *a*, side view; *b*, apertural view.
  7. *Alveolina boscii* (Defrance). $\times$ 12. *a*, front view; *b*, end view. (After Brady.)
  8. *Alveolina melo* (Fichtel and Moll). $\times$ 33. *a*, front view; *b*, end view. (After Brady.)
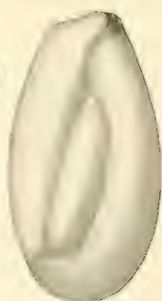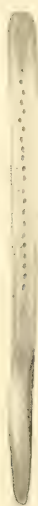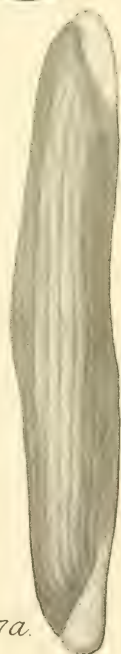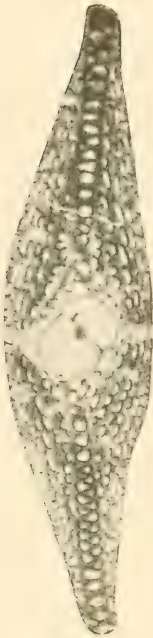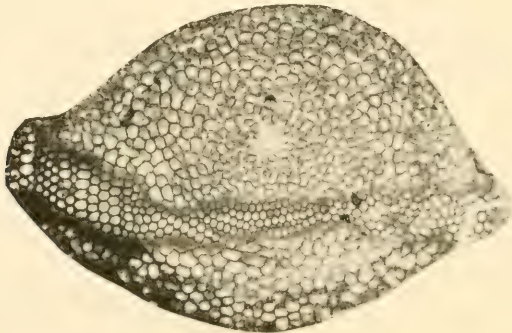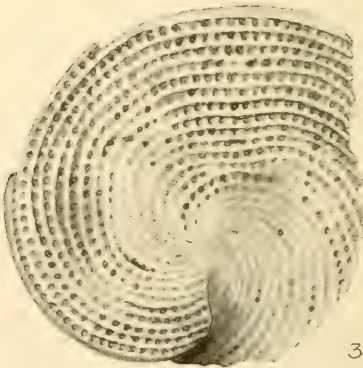
PLATE 16

Fɪɢ. 1. *Orbitolites complanata* Lamarck. $\times$ 30. *a,* surface view; *b,* peripheral
view.
2. *Orbiculina compressa* d'Orbigny. $\times$ 30.
3. *Orbiculina adunca* (Fichtel and Moll). $\times$ 30. Showing interior cham-
ber divisions.
4. *Lepidocyclina macdonaldi* Cushman. Vertical section. $\times$ 20.
5. *Lepidocyclina canellei* Lemoine and Douvillé. Oblique section. $\times$ 20.
Showing narrow zone of equatorial chambers and two broader
zones of lateral chambers.
6. *Orthophragmina minima* Cushman. Vertical section. $\times$ 20.

SOLAR VARIATION AND FORECASTING

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SOLAR VARIATION AND FORECASTING

By C. G. ABBOT

Inasmuch as there are probably still many persons both in Europe and America who doubt the reality of the variation of the sun and, much more, the possibility of applying it to the study of the weather, it has seemed desirable to sum up some of the principal objections which remain in the minds of such persons, to answer these objections, and after that to state some of the principal grounds of a belief in the existence of solar variation.

In order to treat the subject more definitely, I have ventured to assume a personality to represent those who entertain these doubts of the solar variability, and will, in what follows, speak of this personified doubter as " the critic."

The Smithsonian Institution is publishing a group of three papers, Nos. 5, 6, and 7 of Volume 77 of the Smithsonian Miscellaneous Collections, of which this, the first, deals with the objections to the variability of the sun and the principal indications which lead us to believe in it. There are a vast number of straws all of which point in this direction and, combined, make up a very stiff bundle of evidence, but in the limits of a paper of reasonable length, it is not possible to include all of these minor indications, however interesting they may be.

The second paper, by Mr. H. H. Clayton, gives the major results of his investigations of the past two years on the weather conditions of North America in their relations to the variation of the sun.

The third paper, by Mr. G. Hoxmark, to which I have ventured to prefix a short introduction pointing out what seemed to me very interesting features of his results, gives an account of the applications of solar variation to the forecasting of the temperature and rainfall of Buenos Aires, Argentina, for the years 1922, 1923, and 1924.

This group of three papers have such a close connection that I have brought them together in these short paragraphs of introduction.

Although very kind expressions in regard to the accuracy of our work on the solar constant of radiation come to us from all parts of the world, that does not imply universal belief in solar variability.

Professor Eddington, everywhere recognized as one of the foremost astronomers of the world, prepared the article "Astronomy" for the recent supplement of the Encyclopaedia Britannica. Although he has perhaps made more use of our results in his researches than anybody in the world except Clayton, he indicates in that article that appreciable solar variability probably does not exist. Dr. Exner, a leading meteorologist of central Europe, in a recent letter tells me that he and his colleagues are unconvinced. Dr. Linke, in a recent article, paints a vivid picture of the difficulties in measuring solar radiation, and concludes that only an independent investigaton, entirely divorced from the Smithsonian Institution, if it should confirm our results, would justify confidence in the variability of the sun. The summary of astronomical progress for the year 1924, published by the Royal Astronomical Society, mentions several papers adverse to solar variation, and leads the reader to conclude that scientific opinion generally, if not actually in opposition, is still doubtful of solar variation.

We are at the very great advantage compared to our critics that we know all about the work. We are aware of a great many circumstances that disarm criticism, and promote belief. It will be impossible to enumerate all of these here, but I hope to present so strong a case as to fully justify the investigations of Mr. Clayton, who has adopted solar variation as a working hypothesis and sought to see what comes of it. He reports these studies in the next succeeding paper of these Miscellaneous Collections.

Before proceeding, let me state one illuminating consideration. Some writers mention our data for the past 10 or 15 years as if all were of equal value. Really, to speak in a figure, the Washington data of 1902 to 1907 were Prehistoric. As for Mount Wilson results of 1905 to 1908, inclusive, before the invention of the silver disk pyrheliometer, or Fowle's method for estimating total atmospheric humidity, and while we yet used a flint glass prism limiting our spectrum at the H and K lines in the violet—this work is Ancient. Excluding altogether July and August, 1912, the year of the eruption of the Katmai volcano, all Mount Wilson work of 1909 to 1920 can be classed as Medieval. We had then but one station, operating only in summer. We obtained only one determination per day, subject to error from changes of sky transparency and also to errors of computing in the enormous multiplicity of computations used in the reductions of results by Langley's fundamental method. The period from January, 1919, to the present is of another order of accuracy, and represents the Modern period.

All of the Mount Wilson work, excluding altogether July and August, 1912, is useful in the form of averages. It is only since January, 1919, when we have had several determinations each day by a method which avoids errors from the variability of the sky, and much of the time have received results from two stations, that individual values have begun to deserve some confidence. Even yet, they are not up to the class which we hope they will reach within one or two years more. They are still most useful in the form of mean values. This, indeed, is a major reason why correlation coefficients reported by Clayton and by Hoxmark, in discussing their solar forecasts of daily weather conditions, are still low. Very accurate solar radiation data are necessary for that purpose, and we cannot yet quite reach the required degree of accuracy. The methods of reduction of observations for the station at Montezuma are being improved, the Harqua Hala station is being transferred to Table Mountain, California, 2,000 feet higher, and the National Geographic Society is installing, in cooperation with the Smithsonian Institution, a new station in the Eastern Hemisphere. We believe that these improvements will in about two years largely better the results.

DEFENSIVE ARGUMENTS

1. Our critic and I approach this matter from opposite points of view. He has felt that it is necessary to be sure that our solar observations are sufficiently impeccable before he can use them. I was convinced five years ago by figure 1 that one can use them, and having, in cooperation with the Argentine Weather Bureau and with Mr. Clayton, tried experiments in using them, every month reveals new evidences that they can be used. Consider figure 1. The high reputation of Mr. Clayton, whose results are here shown, forbids us to doubt that the march of the curves is real.

What then? Certain observations made on Mount Wilson, California, in the years 1913, 1914, 1915 and 1918 were definitely associated with temperature differences of 6° F. at Buenos Aires, Argentina, 10 days after the event.[1] But, says our critic, this is not a solar but a terrestrial correlation. I am so constituted that, if I

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[1] Owing to errors often occurring at Mount Wilson because of increasing or decreasing haziness during an observation (errors nowadays eliminated in our "new method") no doubt some values in the high and the low groups of solar constants used by Clayton were extreme because erroneous. Thus the range he finds of 5 per cent, he and I now agree was probably not over 2½ per cent in reality. As will be seen in his present paper, such a range of solar constant is large enough to produce notable effects.
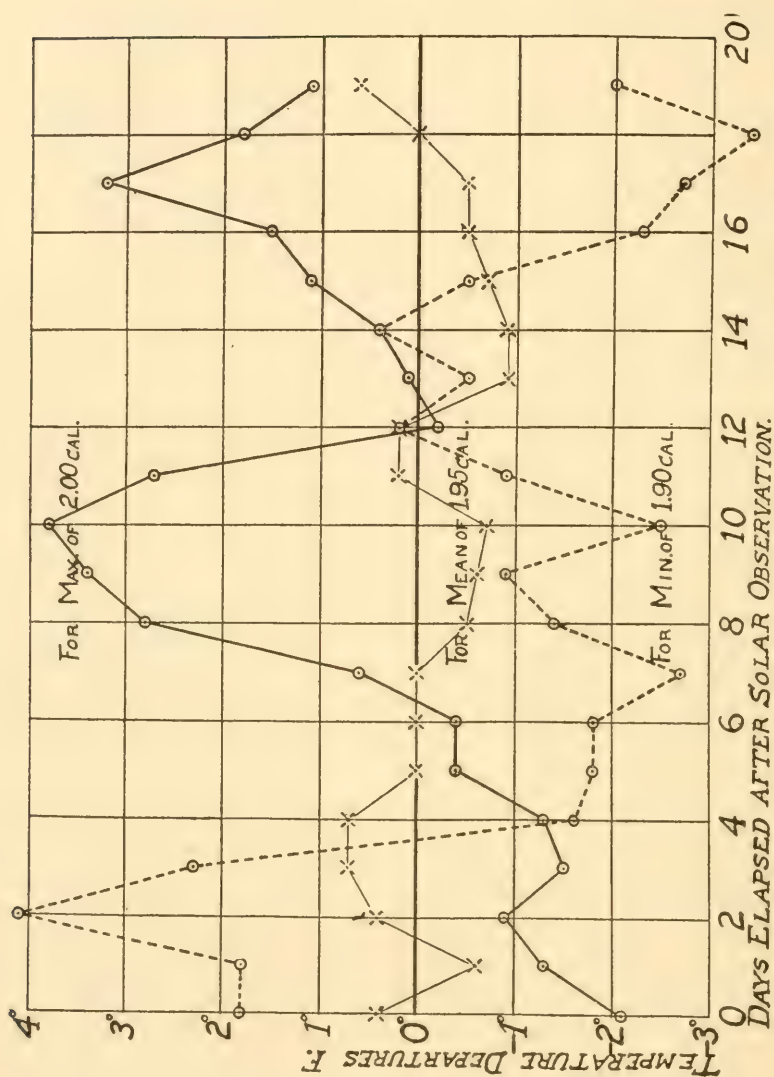
FIG. 1.—Prolonged influence of solar changes on terrestrial temperatures. The three curves each represent mean results for the years 1913, 1914, 1915, and 1918 on the variation of the sun (determined at Mount Wilson) and the temperature at Buenos Aires. The solar values are arranged in three groups, those exceeding 2.00 calories, those below 1.90 calories, and those between 1.94 and 1.96 calories, respectively. The corresponding mean departures of temperature for Buenos Aires from 0 to 20 days after the event are plotted in the diagram.

were a meteorologist, I would not care whether the correlation was through our air, through the sun, or through the star Arcturus; I would try to see whether so fair an opportunity to predict weather 10 days in advance could be reduced to a working basis, not only in Buenos Aires but elsewhere.

Mr. Clayton's paper describes the wealth of interesting results for North America which he has lately obtained in this way. I shall only give two or three examples of Argentine results. Figure 2 [1] shows the solar variation of April, 1920, observed at Calama, Chile,
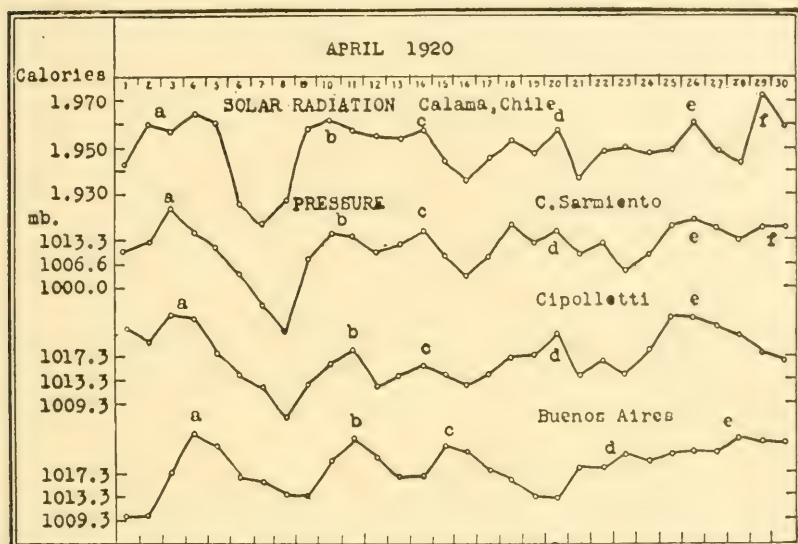
FIG. 2.—Solar variation and atmospheric pressure. Solar-constant values obtained in Calama, Chile, in 1920 are compared with the atmospheric pressure at three Argentine stations.

and compared to the barometric pressure at Sarmiento, Patagonia. Figure 3 [1] shows 3 consecutive weeks of Argentine official forecasts by Mr. Clayton. Figure 4 shows 12 consecutive weeks of Argentine official forecasts by Mr. Hoxmark, Mr. Clayton's successor. All of these forecasts, based on solar variation, are exactly stated numerical predictions of the temperature of Buenos Aires, and are compared to the temperatures afterwards actually observed. The Argentine official forecast is prepared each Wednesday to cover the week beginning Thursday morning. Mr. Hoxmark writes that this solar forecasting is based on our daily observations at Montezuma supple-

[1] From Clayton's "World Weather," Macmillan Co., New York, 1923.
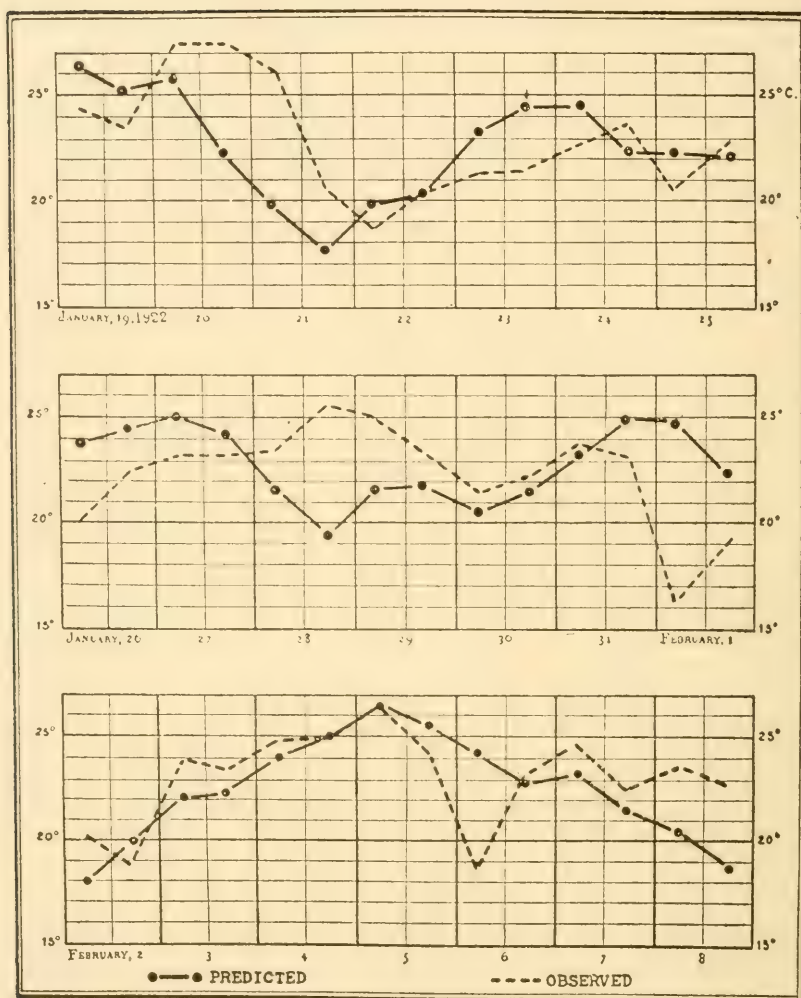
FIG. 3.—Weekly solar forecasts and verifications. The full curves give temperatures at Buenos Aires predicted each Wednesday for the ensuing week beginning Thursday. The actual observed temperatures are given by the dotted curves.

mented by visual observations of the sun in Argentina. It is prepared in a separate branch of the Argentine Weather Service from the ordinary daily forecasts, and independently of them.
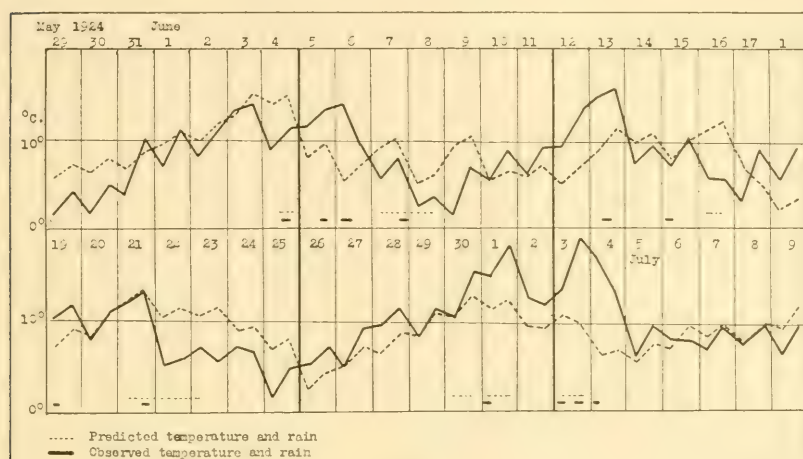
(a)
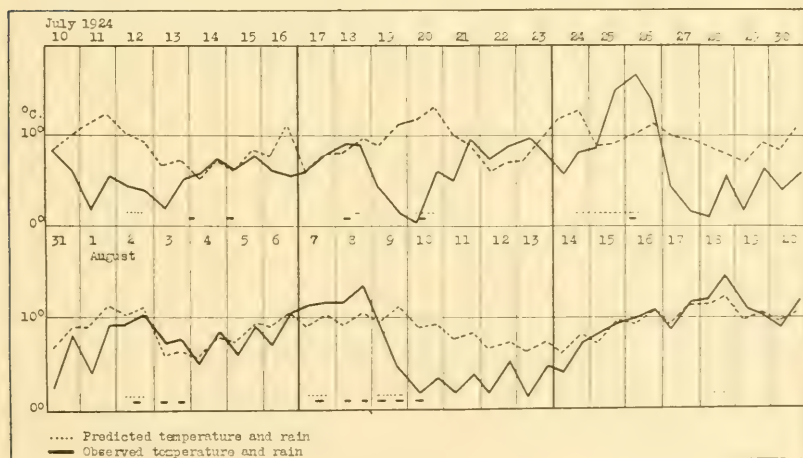
(b)

Fig. 4.—Weekly solar forecasts and verifications. Weekly predicted temperatures and rainfall for Buenos Aires are indicated by the dotted lines, and observed temperature and rainfall by the full lines.

It may seem to some readers that the close agreement shown in figure 2 between the barometer at Sarmiento and solar variation observed at Calama ought not to be expected. They will say that
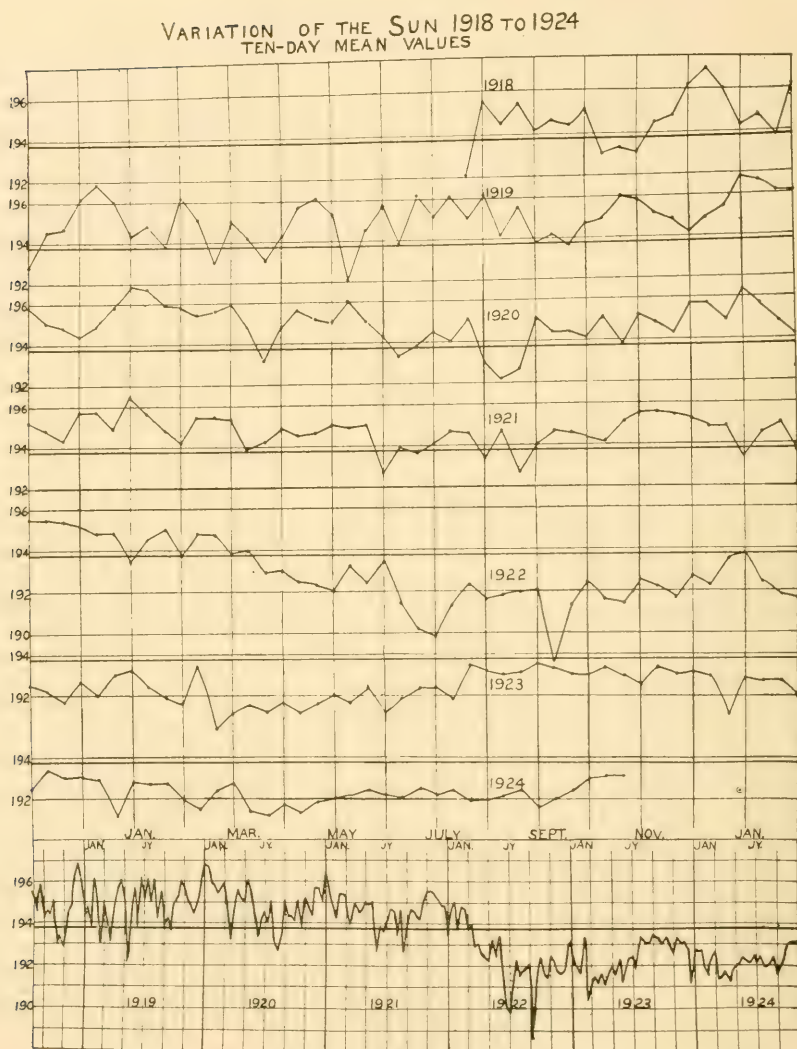
FIG. 5.—Ten-day mean values of the solar constant of radiation, 1918-1924. The seven upper curves give the march of values on a more extended scale, which is condensed into the single lower line of the diagram.

of course temperature varies if the sun does, but that the barometer can only follow temperature, and must lag behind. Please to reflect that, depending on locality, from 10 to 50 per cent of solar radiation outside the atmosphere is absorbed in the atmosphere by smoke, haze, water vapor, and clouds. Since the atmosphere has a very small capacity for heat, the heating effect of this tremendous energy absorption is very quick in the atmosphere, compared to what it would be in the ocean or on the solid earth. Sarmiento is about 100 miles from the Atlantic Ocean, in a very dry, clear region. Rainfall increases in every direction from it except the north. Suppose solar radiation increases. The surrounding air and the air at Sarmiento both immediately grow warmer and expand, but the effect is much greater over the cloudy regions than at clear Sarmiento. Hence, air flows from all around to Sarmiento and raises the barometer there. Similar action centers exist all over the world. They vary in position with annual change of cloudiness and from other causes, which Mr. Clayton's paper discusses.

I now pass to consider certain other criticisms before taking up reasons why we are convinced that the sun varies, and that our observations give substantially the true picture.

2. It has been pointed out by the late Professor Newcomb and by Professor Marvin that there is no evidence of a permanent hot or cold side of the sun. This accords with our results. Such a condition sometimes exists for a few revolutions of the sun, but not permanently. Hence, the solar rotation can be used only with greatest circumspection as a period to forecast by.

3. Professor Marvin has suggested that our recent observations are badly prejudiced by a terrestrial 12-month periodicity. I will not say that there was absolutely nothing of the kind in Mount Wilson observations, but I regard it as nearly or quite nonexistent in later work. He has mistaken a real 11-month periodicity in recent years for a 12-month periodicity. Mr. Clayton discovered the 11-month periodicity over a year ago and reported it to me. Figure 5 shows maxima in January, 1920, and September, 1923, an advance of 4 months in 4 periods. Figure 6, which Mr. Clayton prepared, shows the matter still clearer, because the short period solar fluctuations have been removed by a usual process of smoothing, and we see clearly that the maxima and the minima succeed one another by 11-month intervals. Additional minima occurred in April, 1924, and March, 1925, so that the 11-monthly depression has clearly shown, excepting in May, 1923, ever since the year 1918.

This relates to the past seven years. I am not prepared to insist that it runs back of 1918. Possibly, like the hot and cold side of the sun, which holds sometimes for several revolutions, it may have disappeared in process of time.

In Professor Marvin's 12-month curves from Mount Wilson observations of from 3 to 7 months duration, it is necessary for him to exterpolate over half the year. He combines 15 years of observing. Surely he should have omitted July and August of the year 1912 when the sky was so very turbid from the Katmai eruption that its skylight reaching the pyrheliometer may very likely have led to higher values than its relation to sun-spot minimum would have led us to expect.

FIG. 6.—Eleven-month periodicity in solar variation. The monthly means for solar radiation given in the upper curves are smoothed by a usual process, and show minima eleven months apart, as indicated by the arrows.

The Mount Wilson values of the years 1918, 1919, and 1920 agree in detail with Calama, as I shall show directly, so that they need not be considered as indicating spuriously high summer values. The monthly mean values for the other 11 years are plotted in figure 7. Maxima occur in every month observed except May, and minima occur in every month observed except August. The run of the curves is so varied that one cannot safely conclude how the other unobserved months of the year would have turned out. Professor Marvin has thought that their maxima agree with minima of Chile, northern summer agreeing with southern summer, and northern winter with southern winter. His Mount Wilson and Chile data refer to different years. There is no fair comparison of one year with another when

the hypothesis of solar variation is in the field. When, however, we take Mount Wilson and Calama data of identical dates, as in figure 8, they show no such variance. Figure 8 gives all comparable daily values of 1918, 1919, and 1920. Except for the greater number

Fig. 7.—Monthly mean observations at Mount Wilson, 1905-1917. The heavy smoothed curve and stars near it represent Prof. Marvin's determination of the yearly periodicity in solar radiation, as indicated by the scale at the upper right-hand corner of the diagram.

of poor results at Mount Wilson, the agreement is good and yields a correlation coefficient of about 50 per cent.

There is another objection to using the mean results of the 15 years as Professor Marvin has done. The numerous values of the months June, July, August, and September, which have fixed the

high part of his data, relate to two sun-spot maxima and only one sun-spot minimum, so that they tend to a high level on account of great solar activity. The points for October and November, which are so very intrumental in leading him to his conclusion that winter months would run lower, are brought down by the disproportionate number of very low results of 1911 and 1913, years of sun-spot minimum and little solar activity.

4. In the next place, our critics have argued, from the steadily decreasing average scatter of the solar constant observations, as we have been getting better and better observing conditions, that if
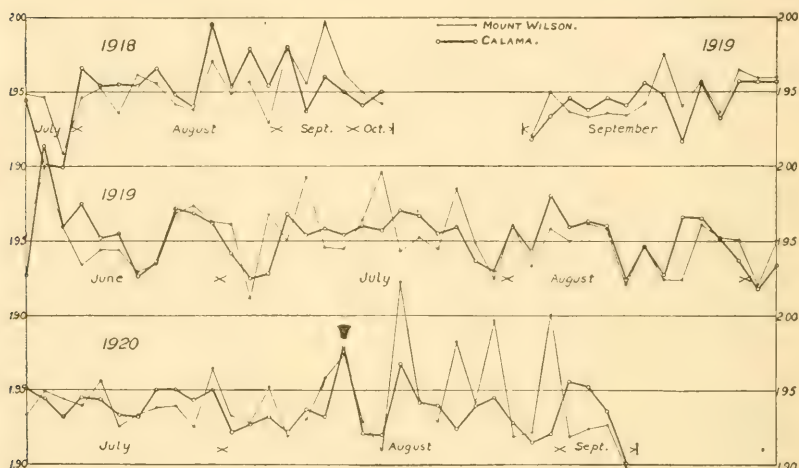
Fig. 8.—Simultaneous daily solar-radiation values at Mount Wilson and Calama, Chile. The days not observed simultaneously are omitted and the curves brought together into continuous broken lines.

we got perfect results no fluctuations would be left. Indeed, according to them, in recent years there is no room left, after allowing for reasonable error, for any appreciable solar variation. With apologies for being a little playful, I would like to put my reply in the form of a short parable.

I meet our critic and say, " Have you noticed, Sir, those tall objects in that field ? " " No," he says, " How tall are they ? " " Why, Sir, I measured them," I reply, " and the measurements are all on this paper." " Let me take it," says he, " and I will look it over and perhaps I will be able to go down and see those objects."

The next time I meet him, I say, " Well, Sir, have you seen those objects which I mentioned to you the other day ? " " No," he answers.

" To tell the truth, I have been examining your paper and I fear you are mistaken." " How so? " I ask. " I have taken the mean value of the heights of the objects as you measured them," he replies, " and find that it is but 4 inches. And, therefore, according to the theory of probability it is excessively unlikely that there are tall objects in the field." " But, Sir," I say, " there are flowering shrubs there at least 6 or 8 feet high, and trees which look at least 30 or 40 feet high." " I regret to differ with you," he answers, " but I am sure my averages are right, and so the mathematics are against you." " But, really, Sir," I reply, " the Washington Monument is in that field. The fact that there are also 17 million blades of grass there cannot shorten it any, though it brings down your average to 4 inches."
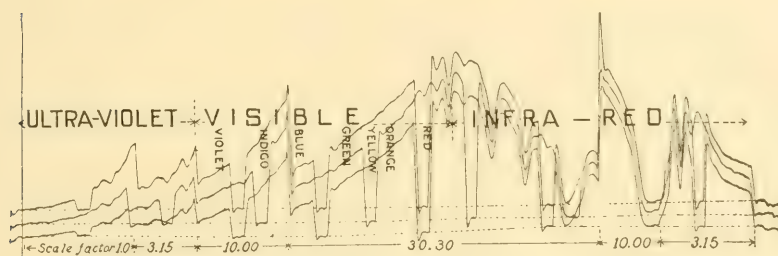
Fig. 9.—Bolographs of the solar spectrum energy distribution.

Similarly, as I see it, the small average scatter of our solar radiation values of recent years about their mean does not preclude us from admitting that some even of the larger deviations are really of solar origin.

5. This leads to our critic's most serious charge. It is suggested that Harqua Hala and Montezuma have lost their characters as independent solar observing stations owing to our methods of removing systematic errors from their data.

My colleague, Mr. Fowle, and I have devoted a great deal of thought and time to a conscientious effort to free the observations of both stations from all terrestrial errors.

Referring to figure 9, our trouble is this: Owing to the greatness of the water-vapor absorption bands in the infra-red spectrum whose areas we have to determine, it is not possible to know just exactly how to draw smooth curves over the bands in that region. We draw as best we can, but we expect to find, and do find, when we examine a large number of solar-constant values, that the results are not independent of the quantity of water vapor prevailing.

What is to be done? Certainly not to leave a known source of error without attempting to remove it. We proceed as astronomers do in correcting star observations for known defects. We separate the results into groups with steadily mounting values of water vapor, plot them, and determine the best corrections for the water vapor effect. That was all we did or could do to correct such systematic errors in the Mount Wilson data.

This would be satisfactory if it were not for the sun's variation at the same time. If we had 50 years of homogeneous observations made at one station to discuss, solar variation could be neglected. It would fall out in the means. But we cannot wait 50 years.

Now comes the part that our critic objects to. We make only one assumption. It is this: A series of observations taken with identical water vapor, identical sky brightness, and all at one observatory, are comparable without any corrections at all. Suppose we take all the observations of one observatory and divide them into such groups, each including only a very narrow range of humidity and sky brightness. Each group of days indicates the solar variation in that group. But there is no way to pass from one group to another, so long as we have only one observatory.

But arrange the values similarly for the other observatory. Again we shall have the variation of the sun indicated strictly within each group, but have no means to pass from group to group. But stay! The days comparable at one observatory fall in various groups at the other. Thus, we find a great many independent determinations, sometimes as many as 20, of each crossing-over factor from one group to another. We take their mean indications, and so are able at length to put all of the observations at each observatory on a comparable footing. Then we compare all the days which are common to both stations and we find that a small, uniform, constant correction, which, of course, does not affect variability at all, is needed to bring them to a common scale.

In all this there is nothing that I can see to make Harqua Hala variations dependent at all on Montezuma variations. After thus getting all *past* observations to a comparable status, we can now go back to eliminate solar variation from the original observations. Having done this, we can go on with each station independently by the usual method of grouping, already explained, so as to get a separate formula for each station, by which all *future* observations of that station are corrected. This also introduces no dependence of one station on the other.

CONSTRUCTIVE ARGUMENTS

Having considered the objections: (1) That it is futile to seek meteorological correlations with imperfect solar observations; (2) that the most naturally to be expected solar variation does not appear; (3) that terrestrial sources of error are obviously still in evidence; (4) that for the past six years our results have shown so small a scatter about the mean that there is no room for solar variation; and (5) that our two stations, intended to check each other's findings, are not really independent, I am ready to take up the constructive part of my paper.

Thesis (*a*).—The theory of probability admits of the belief in the real existence of short-period solar variations, some of which exceed 2 per cent in amplitude.

It is not material to this argument to prove that the scale of Smithsonian measurements is exactly in terms of the 15° calorie. If the average value of the solar constant which we find to be 1.94 calories is really as little as 1.90, or as great as 1.98 calories, it matters not. By expanding or contracting the true calorie slightly, the mean solar constant can be expressed as 1.94. The only question at issue is whether, after this adjustment is made, there are real fluctuations of short period as large as 2 per cent in this conventional value.

Conceive, if you please, an angel to have brought us from heaven the true curve of solar variation covering the period 1920 to 1924, expressed on the same scale as our determinations. We are to inquire, first of all: What will be found to be the average deviation and probable error of our observed curve from the angel's curve?

To determine this question, we have 327 differences between independent daily solar-constant determinations of good character, made at Harqua Hala and Montezuma.[1] I may remark, in passing, that since there is almost three hours difference in longitude, these daily differences are greater, owing to solar variations occurring between measurements, than they would be if the stations observed simultaneously. So our investigation is too liberal to our critics, but I am willing to grant them this advantage.

The average daily difference, Harqua Hala minus Montezuma, is ±0.011 calorie. This is the average daily difference between two series of measurements both affected by accidental errors, and, let us assume, equally affected thereby. Evidently, therefore, the average deviation of either station from the angel's curve is less than 0.011 calorie. It is, in fact, $\dfrac{0.011}{\sqrt{2}}$ as I have demonstrated both theo-

[1] See Smithsonian Misc. Coll., Vol. 77, No. 3, table 4.

retically and by the expedient of drawing several hundred numbers from a bag containing positive and negative numbers equally, and arranged in magnitudes in accord with the probability curve.

So the average deviation of either station from the angel's curve is 0.0078 calorie. The probable error, therefore, of the daily measurement of either station alone is 0.845×0.0078 or 0.0065 calorie. But there are many cases available where both stations observed on the same day. In these cases the probable error of the general mean is $\dfrac{0.0065}{\sqrt{2}}$ or 0.0046 calorie.

I wish it to be realized fully that we do not have to *guess* at the probable error of our determination of the solar constant. Our 327 observations at two stations give abundant material to determine it accurately. As remarked above, we do not pretend to claim that constant errors of scale are included in these small probable errors, which are respectively 0.0046 calorie for general mean results of both stations, and 0.0065 calorie for mean results of a single station. But the possibility of systematic errors of scale has nothing to do with the question of short-period variability.

Having thus obtained the probable error values, we next inquire whether the results, when the long swings of the solar constant which critics have sometimes admitted may be probably real are shut out, still exhibit solar fluctuations. To eliminate the long swings, I make use of the monthly mean values, and take daily departures therefrom. I separate these daily departures from the monthly means into two series, the first containing days observed at both stations, the second containing days observed at one station only. The numbers of observations are 398 and 744, respectively, in the two series.

Taking the first series of 398 days observed at both stations, the numbers of departures from the monthly means, grouped in magnitudes, are as follows:

TABLE I.—*First Series. Departures in ten thousandths of a calorie.*

Departures ....Magnitude ...	0–.0015	.0015–.0030	.0030–.0055	.0055–.0075
Number ....{Observed	84	69	59	49
{Computed ...	69	68	94	56
Departures ....Magnitude ...	.0075–.0095	.0095–.0115	.0115–.0145	.0145–.0175
Number ....{Observed	48	41	14	12
{Computed ...	46	28	20	13
Departures ....Magnitude ...	.0175–.0205	.0205–.0245	.0245–.0295	
Number ....{Observed	11	5	6	
{Computed ...	3	0.9	0.1	

The values marked " computed " are obtained as follows: Taking the value of the probable error as 0.0046 calorie, table 25 of the Smithsonian Physical Tables enables us to compute at once how many departures there should be according to the theory of accidental errors up to the limits ±0.0015, ±0.0030, and so on up, in a series of 398 observations. By subtraction, we obtain the numbers between intervals ±0.0015 and ±0.0030, between ±0.0030 and ±0.0055, *et cetera.* These are the values given in the lines marked " computed " in the table.

It will readily be seen that there is a goodly number of considerable departures, even exceeding ±1 per cent of the solar constant, where the theory of accidental error indicates that should be none at all. No less than 18 of these extra, unexpected, values exceed

TABLE 2.—*Second Series. Departures in ten thousandths of a calorie.*

Departures ....Magnitude ...	0–.0025	.0025–.0055	0055–.0085	.0085–.0115
Number .... Observed	156	136	136	121
Computed ...	152	169	143	107
Departures ....Magnitude ...	.0115–.0145	.0145–.0185	.0185–.0225	.0225–.0270
Number .... Observed	74	53	23	18
Computed ...	74	58	26	10.5
Departures ....Magnitude ...	.0270–.0310	.0310–.0350	.0350–.0390	.0390–.0430
Number .... Observed	15	4	4	4
Computed ...	3.0	1.3	0.2	0.0

± about 1 per cent. This tends to prove that short-period solar variation cannot be denied a real standing in court. We shall treat long-period changes separately.

We are at less advantage when we take the second series, because the probable error is now 0.0065 instead of 0.0046 calorie. Nevertheless, the conclusions are much the same, as shown in the table. There were here 744 cases in all, of which 30 more than the expectancy exhibit departures exceeding ± about 1 per cent, and 4 exceed ± about 2 per cent.

Figure 10, based on table 1, shows strikingly the excess of large observed departures over those predicted by the theory of accidental errors.

Thesis (b).—Consistent evidence of solar variation is found in the results of both stations.

In figure 11, I show monthly mean values of both stations for the years 1920 to 1922. The curves cover one of the most interesting

periods of solar change which we have discovered. It will be seen that not only the long enduring downward march, but the temporary recoveries of solar radiation are often duplicated in the results of Montezuma and Harqua Hala.

COMPARISON OF OBSERVED
AND COMPUTED
NUMBERS OF DEPARTURES OF
SOLAR CONSTANT VALUES.
FROM 398 OBSERVATIONS.

| OBS.→ | 84 | 69 | 59 | 49 | 48 | 41 | 14 | 12 | 11 | 5. | 6. |
| COMP→ | 69 | 68 | 94 | 56 | 46 | 28 | 20 | 13 | 3 | 0.9 | 0.1 |

NUMBER RATIO: OBS./COMP.

RATIO OF DEPARTURES TO PROBABLE ERROR.
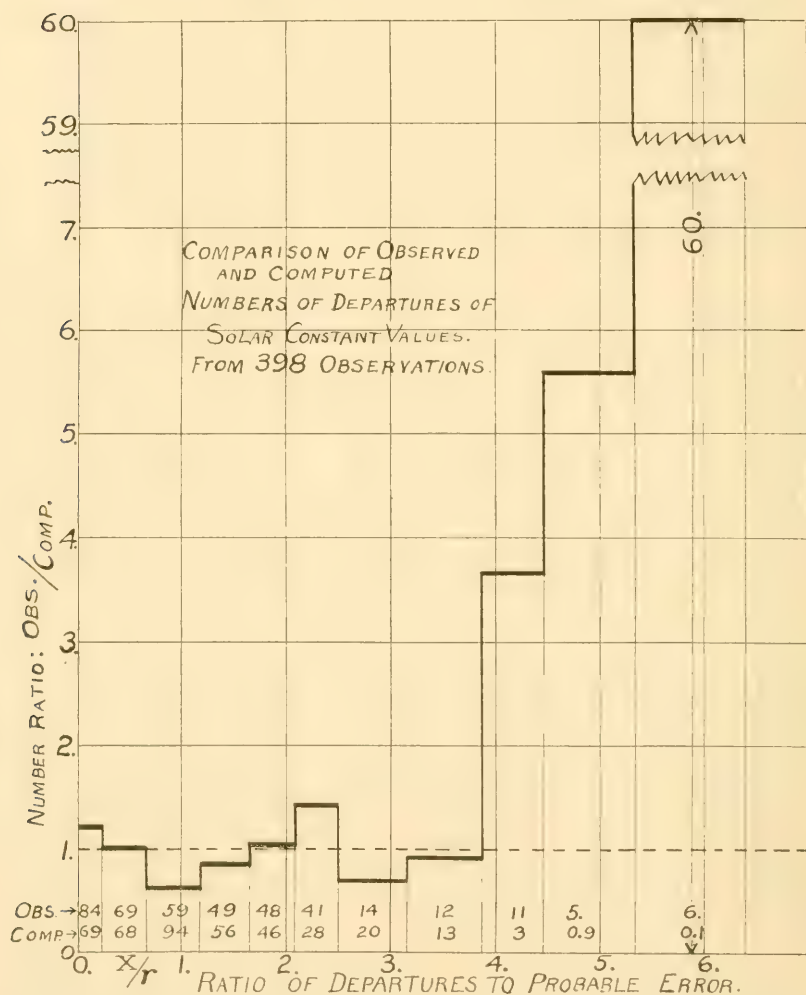
FIG. 10.—Theory of probability indicates possible solar variations of short period.

Figure 5 gives 10-day mean values of solar radiation from 1918 to 1924. This indicates that the low period of solar radiation still continues, although recently with a rising tendency.

FIG. 11.—Monthly mean solar-constant values and individual results of 1920-1922 at Harqua Hala and Montezuma. The curve shows the great fall of solar radiation beginning February, 1921.

Figure 12 shows a direct comparison of Montezuma and Harqua Hala from 1920 to 1924. Over 300 days common to both stations have been arranged in 16 groups of gradually increasing mean solar-constant values, as indicated by Montezuma observations. These identical groups of days' results were also averaged for Harqua Hala. Of course, in this way the range shown at Harqua Hala must
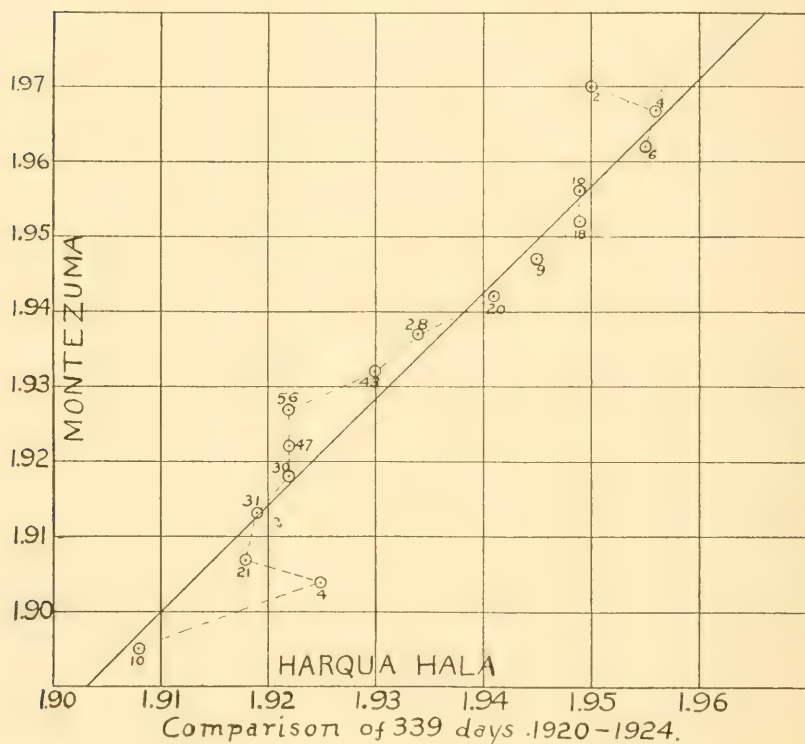
FIG. 12.—Correlation between Montezuma and Harqua Hala on solar variation.

necessarily be less than that shown at Montezuma, because some of the extreme Montezuma values will be extreme on account of error of observation, and will not be extreme at Harqua Hala. I have, therefore, given Harqua Hala a more open scale so as to incline the line at 45°. The correlation is obvious.

Thesis (*c*).—Observed changes in solar radiation are clearly associated with visible changes in the sun.

Figure 13 shows a comparison of Wolf sun-spot numbers with all of our thousands of solar-constant values obtained from 1905 to

1924. Mean Mount Wilson values, grouped with gradually increasing spot numbers, are given by crosses. Modern values of 1918 to 1924 from Montezuma and Harqua Hala observations are indicated by circles. Evidently higher solar constants are associated with greater solar activity. Some of the irregularities of the data are probably due to the counteracting tendency associated with crossing of the sun's central meridian by spots, as will be mentioned below.
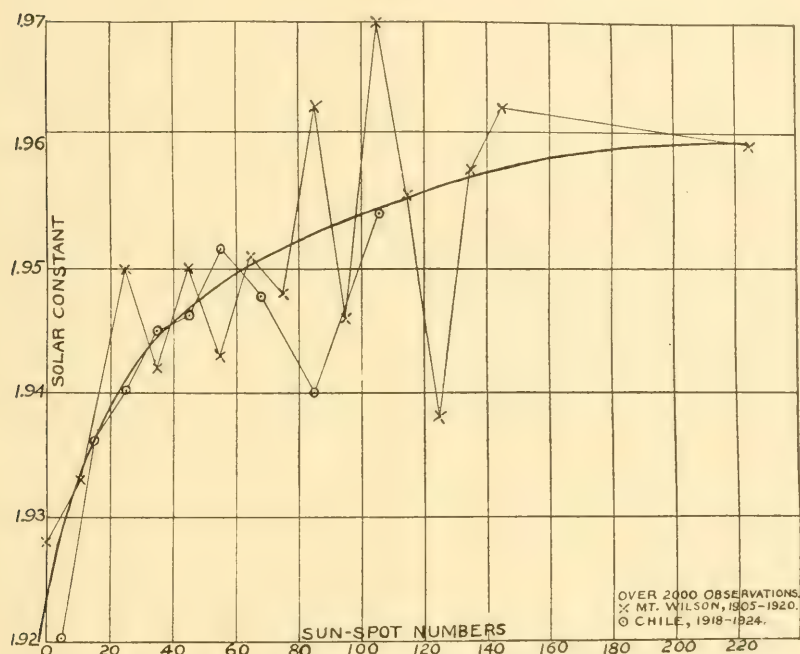
FIG. 13.—Increased sun-spot activity brings higher solar-constant values.

My colleague, Mr. Fowle, has compared the results published by the Observatory of Ebro on areas of sun spots and of flocculi with our solar-constant values of 1921-1923. Figure 14 shows these relations. It is clear that a fairly close connection appears between flocculi and solar constants, closer than prevails between sun spots and solar constants. The extraordinary drop from 1921 is confirmed.

Solar changes of *short* period also accompany observed changes in the sun's visible appearance.

In the summer of 1923, being at the Mount Wilson Observatory, Director W. S. Adams and I took all the simple photographs of the sun which had been made there from August, 1918, to July, 1920,

and compared them with the solar-constant values secured by Smith-
sonian observers at Calama, Chile. We were soon perfectly agreed
that we perceived the following relation: When a sun spot, or group
of sun spots, crosses the central diameter of the solar disk, in course
of the solar rotation, the next following day almost invariably shows
a minimum value of the solar constant. We perceived this to hold
in so very large a proportion of cases that all doubt of it was
dispelled.
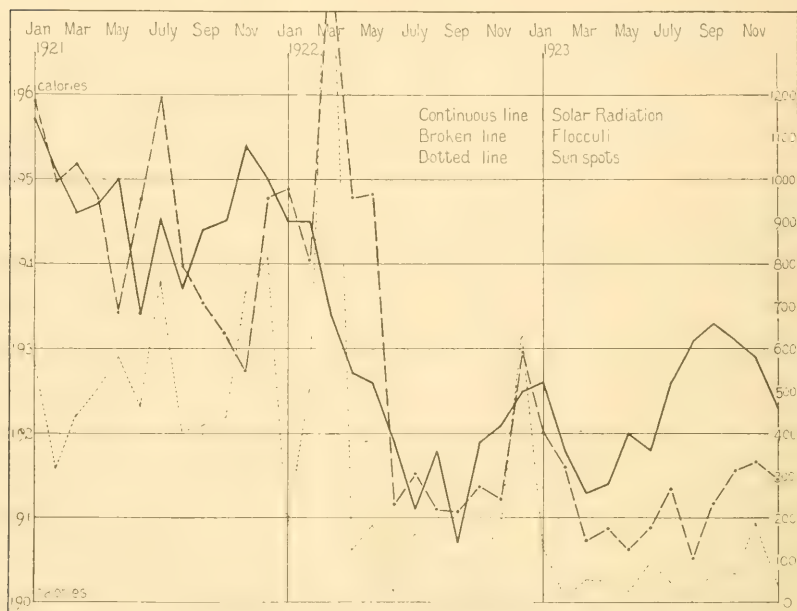
FIG. 14.—Comparison of solar variation with variation of visible phenomena
on the sun from results of the observatory at Ebro.

A conspicuous case occurred in March, 1920, as shown in figure 15.
More recently, Mr. Clayton has made a quantitative examination of
this relation extended over several years of observation. His result
entirely confirms ours. Still more recently, my colleague, Mr. Fowle,
has taken the quantitative data of the Observatory of Ebro in Spain,
where they give sun-spot areas within 15° of the sun's center. He
finds a plain correlation of the same sort. Some examples of it are
shown in figure 16. Large spotted areas near the sun's center are
nearly always associated with lower solar constants.
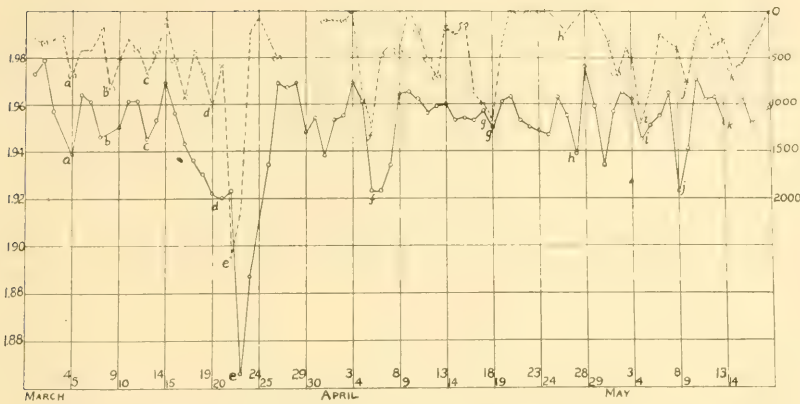
FIG. 15.—Variation of the sun, March to May, 1920. The lower curve (scale at the left) gives values of the "solar constant of radiation" observed by Smithsonian men at Calama, Chile. The upper curve (scale at the right) gives areas, in millionths of solar hemisphere, of calcium flocculi, measured at the Observatory of Ebro in Spain. Only flocculi within ±15° of the central solar meridian are included. Two scales of days are given, as the upper curve is displaced 1 day forward. Coincident depressions are indicated by letters.
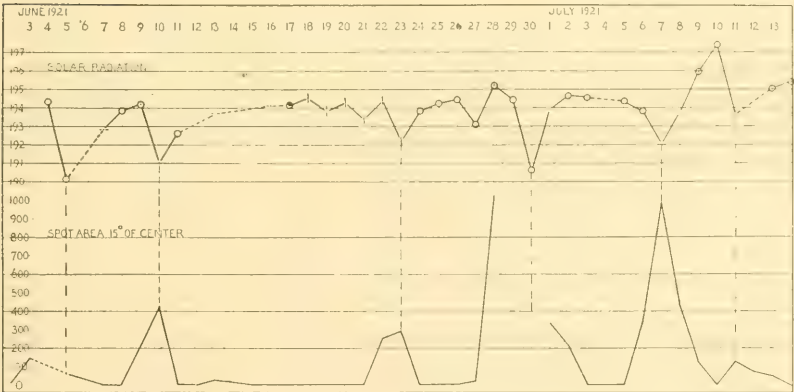
FIG. 16.—Central sun spots and solar radiation. The lower curve is from publications of the observatory at Ebro.

Another relation has been found by Mr. Clayton. He speaks of it in his paper. When faculae are conspicuous, high solar-constant values may be predicted. Mr. Clayton has gone further. He has made visual solar observations daily with a telescope in Canton, Mass., on every available day for nearly a year, and has sent me a letter the same afternoon in which he has predicted what the solar constant would be 5 days after. After these predictions had been maintained for 7 months, I compared them with our observations.
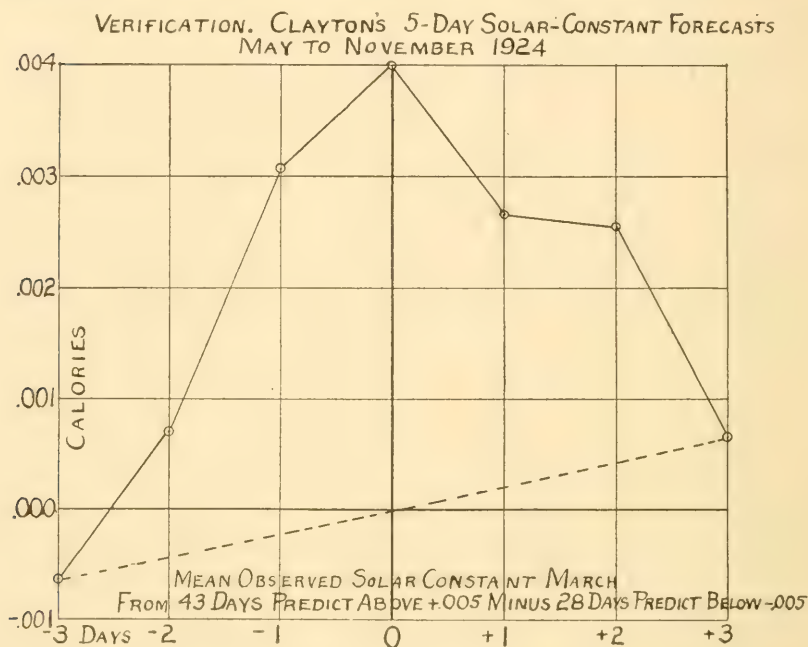
Fig. 17.—Verification of Clayton's solar-constant forecasts. The mean march of solar variation from three days before to three days after Clayton's forecasts is compared for those dates on which he predicted .005 calorie above with those on which he predicted .005 calorie below normal.

I found a strong correlation which reached its maximum exactly on the day he predicted for, as shown in figure 17. Mr. Clayton has discovered other relations between solar changes and faculae observed on the solar disk.

Hence, we may claim that the visible appearances of sun spots, faculae, and flocculi on the sun are clearly associated with the short-period variations of the solar constant.

Thesis (d).—Solar changes are localized to short wave lengths.

The question arises whether increase of the solar constant implies increase of intensity in equal proportion over the whole spectrum. To test this, we have used a number of the best determinations made by the fundamental method of Langley. We separated these into groups of high, medium, and low solar constants, and took mean values of the spectrum distribution outside the atmosphere. We divided the numbers representing the distribution curve for low solar constants into the corresponding numbers representing higher ones, first having reduced the curves to such a scale of ordinates as
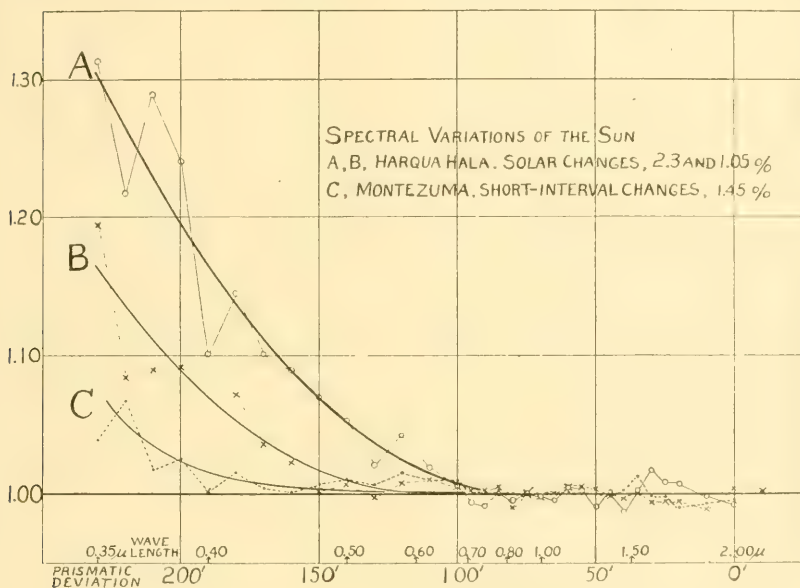
FIG. 18.—Solar variation localized in the violet and ultra-violet.

to represent the change in solar constant by the change of area included under them. Figure 18 shows the result. Curves A and B are for Harqua Hala values of high and medium solar constant as compared to low. These represent what happened in the big swing in solar-radiation level from 1921 to 1923. The 1921 values were high because the blue, violet, and ultra-violet were high. The green, yellow, red and infra-red were almost unchanged.

Curve C is from recent Montezuma values of 1924. It represents, therefore, nothing but short-period solar fluctuations. No care was used in computing Curve C to reduce the areas under the curves to proportionality with the solar constant. However, it will be seen

that here, too, the change was mainly in the blue, violet, and ultra-violet spectrum.

There are evidently two kinds of solar change. The long-period swings are related to the total solar activity. Great visible activity in the sun, such as numerous sun spots, faculae, or prominences, like stirring a fire, brings hotter radiating surfaces to the front, and produces higher solar constants.

But on the other hand, whenever a sun spot crosses the sun's center, it carries along with it a cloudlike effect, not a cloud, of course, but a diminished transparency. When this diminished transparency points towards the earth, we have for a few days lower solar constants.

Both kinds of change affect the short-wave rays of the spectrum more than the long-wave rays. This is, of course, what one would expect. Increased effective solar temperature, attending increased activity, would produce its larger effects at shorter wave lengths, in accord with the Wien-Planck Law of temperature radiation. Increased opacity of the solar envelope, just like increasing opacity of the earth's atmosphere, would also produce its larger effects at shorter wave lengths, quite in accord with our own observations of atmospheric transmission coefficients. It is yet too early to decide by a comparison of Curve B with Curve C that there is a real difference in the quality of these spectrum changes, depending on the character of the solar change involved. Yet so far as this evidence goes, it indicates a less pronounced contrast between short- and long-wave rays in spectrum change for short-period solar variations than for long-period ones.

CONCLUSION

To sum up:

1. It is not necessary to wait for perfectly impeccable solar-constant determinations to determine changes of the sun's radiation well enough for useful comparison with meteorological phenomena. Better values, however, will soon be available.

2. Such comparisons as have been made indicate that a higher accuracy than the present in solar-constant determinations will be needed to yield high correlations in forecasts for individual days, but that where mean values can be used, as in forecasts for weeks or months, present values are fairly satisfactory.

3. There is no reason to think that the independence of the two solar radiation stations, Montezuma and Harqua Hala, has been lost on account of means used to eliminate systematic errors.

4. The probable error of a fairly satisfactory mean daily value for one of these stations alone is 0.0065 calorie, and for a fairly satisfactory daily mean value derived from results of both stations it is 0.0046 calorie.

5. From a study of numbers of observations, and their departures from the monthly means, in connection with these values of the probable error, it is found that many more departures of magnitudes of from 1 to 2 per cent are found than should arise from accidental error. This investigation ignores the still larger departures of longer periods which attend changes in solar activity.

6. The theory of probability allows us to entertain a belief in short-period solar variations as well as in long-period ones.

7. Both short- and long-period solar variations are associated with observable changes in the appearance of the sun.

8. Two stations 4,000 miles apart agree in disclosing both short- and long-period solar variations of several per cent amplitude.

9. Both short- and long-period solar variations are attended by alterations in the form of the solar energy-spectrum distribution. These alterations are far greater for short-wave rays than for long-wave rays.

10. There is a twofold cause for solar variation. Long-period fluctuations are due to changes in solar activity. Short-period fluctuations are due to obscurations in the solar atmosphere, which, rotating with the sun, produce depressions whenever they point towards the earth. For this cause, solar variation is not closely correlated with sun spots, because, though numerous sun spots betoken great solar activity and high solar constants, yet each individual sun spot, as it passes through the sun's center, carries its obscuring tendency, and produces a temporary depression of solar radiation as viewed from the earth.

SOLAR RADIATION AND WEATHER

OR

FORECASTING WEATHER FROM OBSERVATIONS OF THE SUN

BY

H. H. CLAYTON

(Publication 2826)

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On my return from Argentina in 1922, where in 1918 I had initiated the making of weekly weather forecasts from solar data combined with the ordinary meteorological observations at the earth's surface, Dr. C. G. Abbot manifested a desire that I should test the possibility of such forecasts for the United States. The cooperation financially and personally of Mr. John A. Roebling has made possible the necessary researches and tests.

In order to make forecasts for the United States, it was necessary first to determine the meteorological sequences, if any, which follow changes in the amount of solar radiation as observed at the astrophysical observatories of the Smithsonian Institution.

The first step in the investigation was to divide the observed solar radiation values into grades. This was done for the interval July, 1918, to September, 1922, which included all the solar data available at that time since the beginning of continuous observations in Chile. The observations in Chile for the summer of 1918 were supplemented by observations at Mt. Wilson, and since October, 1920, by observations at Mt. Harqua Hala in Arizona. The grades were taken .010 calorie apart, beginning with the lowest measured values, around 1.860 calories per square centimeter per minute, and proceeding step by step to the highest values, around 2.030 calories per square centimeter per minute. The observed frequencies of the different intensities are given in table 1 and are plotted in figure 1. The frequency

TABLE 1.—*Frequency of Occurrence of Different Intensities of Solar Radiation, July, 1918 to September, 1922.*

Solar Rad. in Calories Per sq. cm. per m.	Number of Cases	Solar Rad. in Calories Per sq. cm. per m.	Number of Cases
1.861–1.870	2	1.951–1.960	235
1.871–1.880	4	1.961–1.970	132
1.881–1.890	13	1.971–1.980	37
1.891–1.900	21	1.981–1.990	19
1.901–1.910	29	1.991–2.000	6
1.911–1.920	65	2.001–2.010	1
1.921–1.930	117	2.011–2.020	6
1.931–1.940	180	2.021–2.030	2
1.941–1.950	249	2.031–2.040	0

of error curve which would give the best fit for these observations was determined from a plot on an arithmetical probability diagram in which the probability integral is expanded so that plotted values of the integral follow a straight line. The curve thus derived is drawn through the values in figure 1.

This curve indicates a mean variability in the solar radiation values of ± .011 calorie (about 0.6 per cent). That is, 50 per cent of the observed values will not differ more than this amount from the mean value 1.945, while 50 per cent will show a larger deviation. According to the curve, only two per cent of the observations deviate as much as 2 per cent (0.039 calorie) from the mean value. That
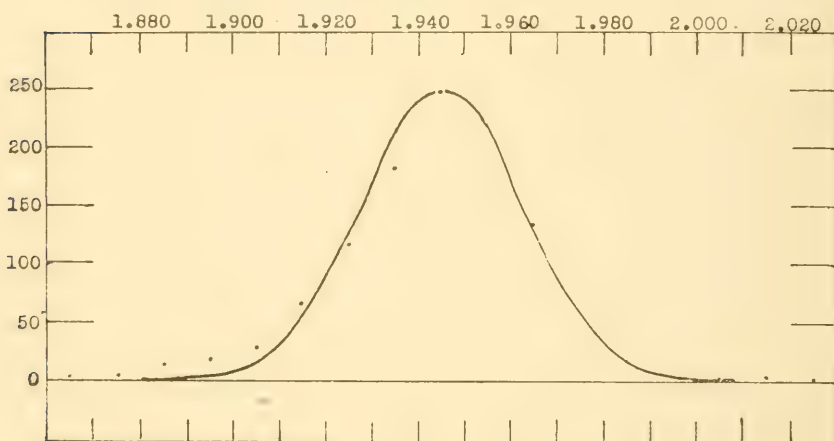
FIG. 1.—Frequencies of occurrence of different intensities of solar radiation, July, 1918, to September, 1922.

is to say, very few observed values should fall below 1.906 and very few rise above 1.984. The observed frequencies of very low and very high values exceed the theoretical expectancy.

In dividing the observations into high, low, and medium, it was found most convenient to call all values above 1.960 high values, and all below 1.931 low values. Separating the observations into these two classes, they were compared with the 8 a. m. observations of pressure at various stations in the United States and Canada, in order to discover what relations might exist at the selected places between solar heat variations and weather changes. The mean results are given in tables 2 to 5, for the interval beginning two days before the solar heat measurements and ending 12 days after. The results for the winter half-year given in tables 2 and 3 are plotted for

TABLE 2.—*Mean Pressures for Each Day from Two Days Before to 12 Days Following Observed Solar-Radiation values Above 1.960 Calories—Winter Half-Year.*

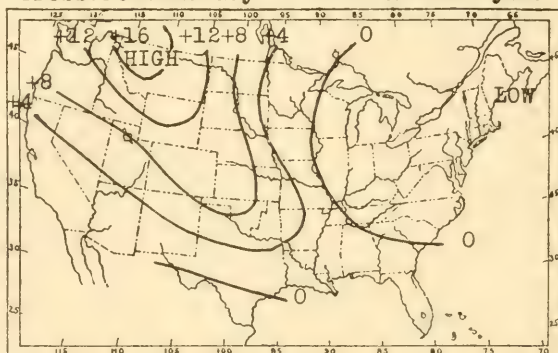| Station	Days Before		Days After														Normal
	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago	.080	.037	030	.074	101	.067	.034	.049	.067	103	057	091	.078	.060	.097	.067
Father Point	.956	.983	.959	.974	091	080	.070	.009	.989	.973	.996	.984	003	.023	.959	.998
Galveston	.110	097	088	109	108	.099	.093	.088	.103	.107	098	.117	.105	.106	.112	.089
Hatteras	.070	092	.077	.073	113	.137	.092	.101	.090	.127	.119	101	.126	.116	.073	.110
Jacksonville	.123	.133	.122	.112	.135	.137	.117	.133	.132	.145	.132	.117	.141	.130	.106	.123
Kamloops	.022	.028	.046	011	.005	.017	.070	.043	.047	048	044	.028	038	.045	.046	.024
Key West	.068	.071	060	055	.065	.071	.065	.065	.072	.074	.061	.057	.067	.066	.065	.057
Los Angeles	.042	.051	056	049	013	037	.036	.052	.044	.050	.033	.024	031	.049	.039	.031
Memphis	.159	.138	.126	.145	.167	.131	.144	.143	.148	.172	.133	.167	.162	.145	.156	.144
New York	.062	.082	.064	.064	082	.150	.088	.069	.077	.090	.120	.091	.140	.108	.075	.094
North Platte	.046	.054	104	087	.051	.058	.054	.077	.083	.069	.089	071	.065	.083	.093	.074
Portland, Ore.	.069	.084	.084	080	.056	.045	.097	.097	.099	.083	.069	.054	.068	.077	.076	.066
Prince Albert	.990	.984	.004	011	972	.005	012	004	991	.032	.036	031	039	.049	.045	.988
Roswell	038	032	.058	067	034	.037	038	.051	.059	.057	.054	.049	033	.064	.050	.033
Salt Lake	.084	.090	125	104	085	.070	075	102	106	098	.102	.082	079	.100	.078	.075
San Francisco	.088	108	.099	096	079	.085	.087	.092	.100	091	.073	.056	076	084	.069	.073
White River	.981	.944	.953	013	042	990	.974	964	971	970	.972	013	005	.009	.021	.978
Winnipeg	.046	026	.054	046	037	.051	021	.052	.030	049	087	053	075	.077	.093	.029

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

TABLE 3.—*Mean Pressures for Each Day From Two Days Before to 12 Days Following Observed Solar-Radiation Values Below 1.931 Calories—Winter Half-Year.*

Station	Days Before		Days After														Normal
	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago	.082	.053	.045	.047	.011	.052	.106	.075	.056	.094	.117	.066	.078	.068	.048	.067
Father Point	.957	.020	.976	.954	.954	.946	.993	.077	.025	.946	.997	.039	.017	.047	.035	.998
Galveston	.066	.059	.062	.057	.075	.099	.111	.089	.091	.100	.091	.060	.044	.056	.063	.089
Hatteras	.136	.109	.094	.091	.089	.085	.150	.140	.122	.086	.130	.150	.178	.134	.099	.110
Jacksonville	.121	.105	.104	.103	.098	.104	.132	.131	.126	.129	.140	.145	.124	.114	.108	.123
Kamloops	.014	.003	.049	.023	.007	.014	.988	.068	.018	.031	.005	.998	.008	.989	.982	.024
Key West	.042	.044	.041	.040	.035	.040	.052	.054	.057	.058	.060	.057	.051	.050	.044	.057
Los Angeles	.006	.008	.006	.020	.019	.012	.032	.028	.029	.012	.014	.027	.026	.023	.027	.031
Memphis	.131	.117	.115	.125	.117	.152	.186	.149	.146	.167	.177	.125	.142	.131	.120	.144
New York	.108	.106	.096	.050	.086	.042	.102	.123	.086	.060	.128	.139	.093	.140	.097	.094
North Platte	.070	.077	.084	.120	.064	.108	.080	.062	.123	.069	.032	.045	.074	.076	.057	.074
Portland, Ore.	.056	.066	.092	.055	.028	.022	.022	.067	.089	.086	.032	.060	.065	.066	.032	.066
Prince Albert	.946	.956	.948	.944	.957	.998	.004	.992	.985	.950	.960	.993	.961	.910	.946	.988
Roswell	.020	.018	.023	.025	.025	.034	.038	.006	.030	.036	.978	.982	.027	.019	.011	.033
Salt Lake	.045	.045	.074	.076	.064	.054	.036	.060	.066	.069	.030	.039	.086	.052	.078	.075
San Francisco	.036	.055	.063	.053	.037	.025	.055	.079	.072	.063	.061	.081	.083	.067	.062	.073
White River	.994	.965	.955	.934	.921	.986	.024	.007	.942	.984	.967	.955	.961	.947	.971	.978
Winnipeg	.981	.000	.943	.996	.985	.018	.054	.023	.048	.000	.989	.034	.025	.979	.990	.029

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.
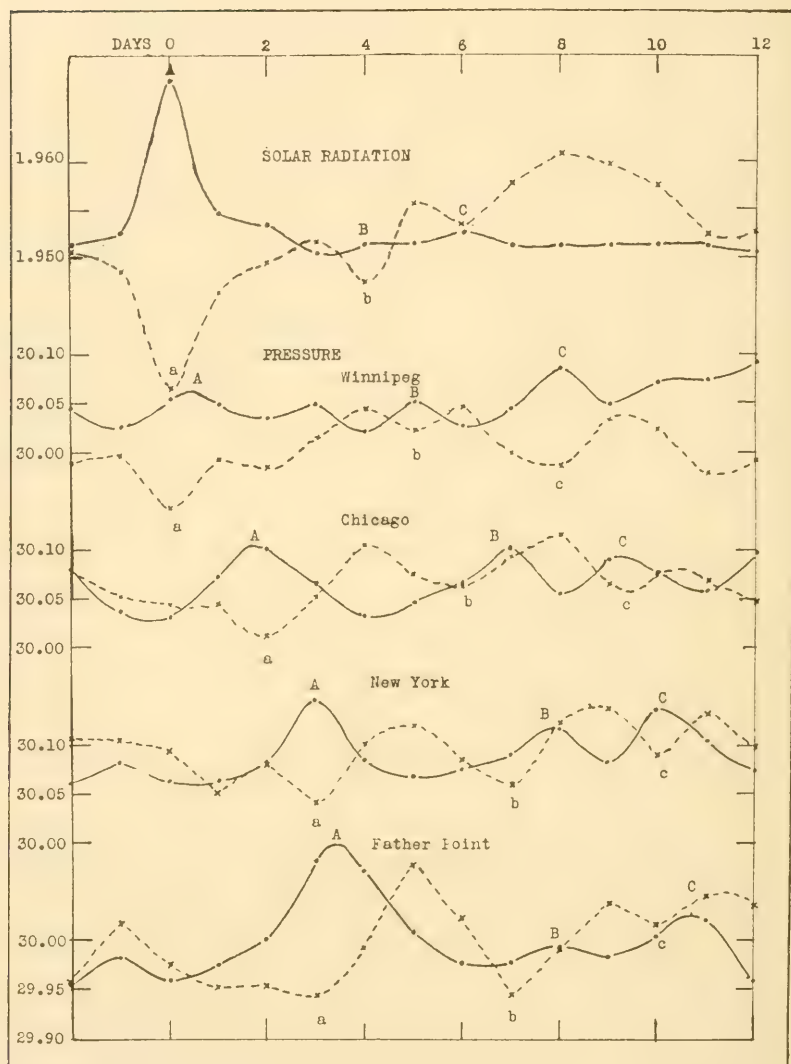
FIG. 2.—Comparison of solar radiation and atmospheric pressure in latitudes 40°-50° N., winter half-year, 1918-1922.
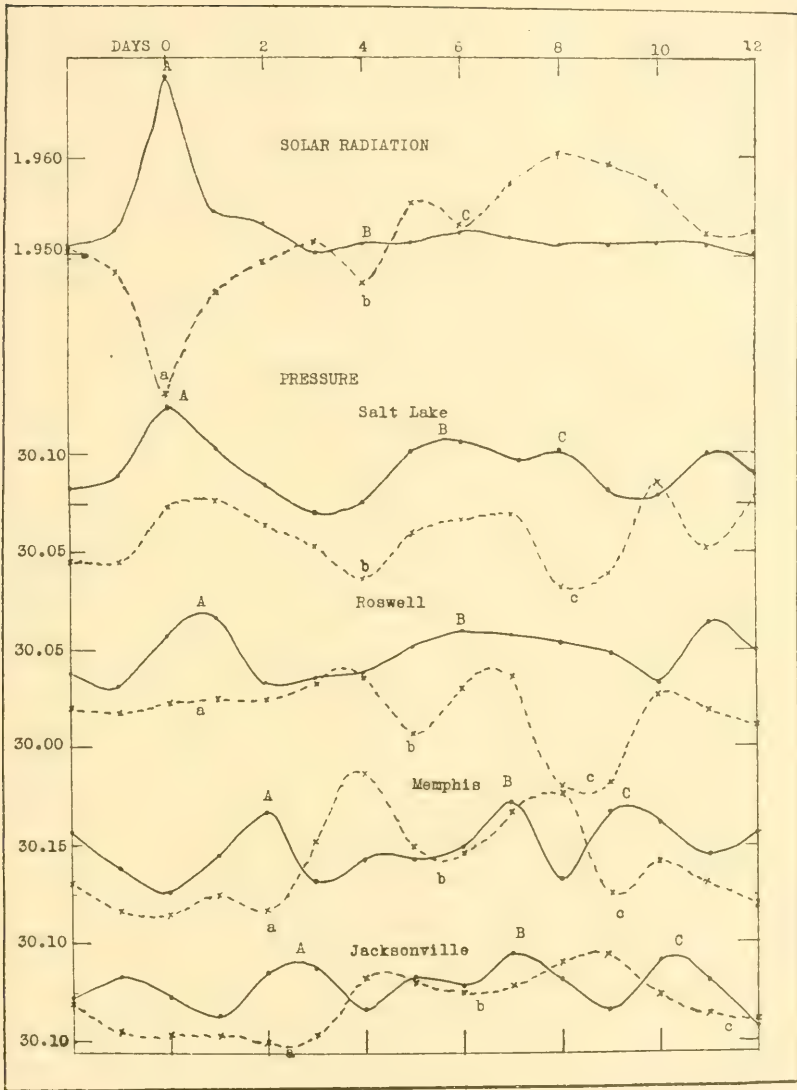
FIG. 3.—Comparison of solar radiation and atmospheric pressure in latitudes 30°-40° N., winter half-year, 1918-1922.

stations between 40° and 50° N. in figure 2, and for stations between 30° and 40° N. in figure 3. The continuous curve in the upper part of the diagram shows the mean solar radiation, and those below it show the mean atmospheric pressure preceding and following high values of solar radiation. The broken curve in the upper part of the diagram shows the mean solar radiation, and those below it show the mean pressure preceding and following low values of solar radiation.

The first thing to be noted in these curves is that the pressure following high values of solar radiation oscillates in opposition to the pressure following low values of solar radiation. The high points in the continuous curves correspond in general to low points in the broken curves. This is particularly true of the northern stations shown in figure 2, and extends to 12 days following the observations. This fact clearly indicates a relation between solar radiation and pressure in the United States and Canada. The only marked exception is in the case of the mean pressure at Salt Lake City, following low values of solar radiation.

The next thing to be noted is that the maxima and minima of pressure appear first at stations in the central United States and Rocky Mountain region, and occur later at stations in the eastern United States, showing a progressive movement from west to east.

The third thing of importance is that the first maximum of pressure occurs at western stations of the United States and Canada on the same day as the observed high values of solar radiation. This is true for Salt Lake City, Portland, Ore., and Winnipeg, Canada, showing that there is a center of action in the general region between Winnipeg and Portland, and the primary result follows the change of solar radiation with surprising rapidity. This maximum is indicated by the letter "A" in figures 2 and 3. The secondary maxima, " B " and " C," probably follow the normal sequence of phenomena on the sun after the occurrence of high solar values, but this cannot be determined with certainty owing to the broken series of solar observations. These observations are so interrupted as to make it very difficult to obtain accurate means for succeeding days. Except at the far western stations the relation of the minima of pressure to low values of solar radiation was in general the same as that of the maxima of pressure to high values of solar radiation. This evidence is more striking, however, for Buenos Aires, Argentina, as shown by figure 4. The figure gives a comparison of the mean solar radiation for successive days following high observed values and mean temperatures at Buenos Aires for the same days. The point

marked "A" shows the day of the high values, and " B," " C," etc., show succeeding maxima of solar radiation disclosed by the mean results. It is seen that the succeeding maxima are reflected in the mean observed temperatures at Buenos Aires for the same days and probably cause them, since, omitting the solar maximum "A," the succeeding solar changes and the following temperature changes at Buenos Aires show a minus correlation of 0.66 for the 30 days. In the plot in figure 4 the temperature is inverted, that is, high values are plotted downward and displaced 3 days to allow for lag in temperature changes.
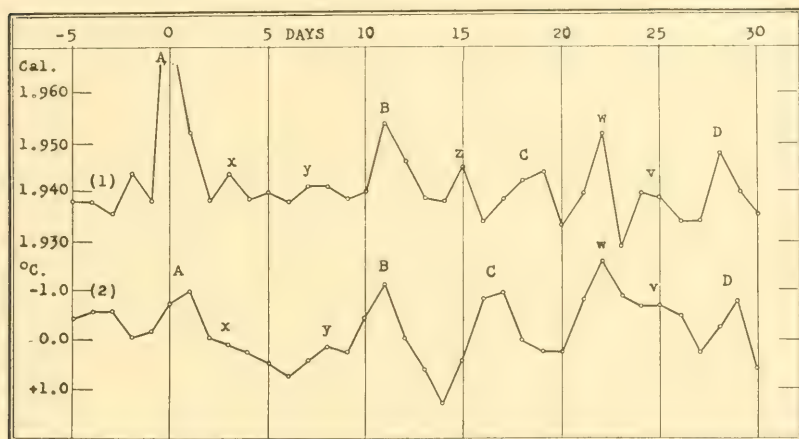
FIG. 4.—Mean values of solar radiation and of temperature at Buenos Aires preceding and following maxima of solar radiation, 1909-1918. (1) Mean values of solar radiation preceding and following maxima above 1.990 calories. (2) Mean temperatures in Buenos Aires 3 days later (inverted).

The contrast between the mean pressures found with low values of solar radiation and with high values is shown in figures 5 to 7. The mean difference between the pressure accompanying low solar values and that accompanying high values on the day of observation is shown by the upper chart in figure 5 to exceed .08 of an inch with the high pressure central near the middle of the North American continent on the eastern Rocky Mountain slope. This high pressure area on succeeding days drifts eastward as shown by the lower charts in figure 5 and the charts in figure 6. Three days after the day of the solar observation it passes off the east coast of the United States. It is followed by a low pressure which forms at a lower latitude and in turn drifts eastward to the Atlantic coast. This change of latitude with decreasing radiation has significance as will be seen later.

Increase of SOLAR RAD. from below 1.931 to above 1.960

Pressure same day   Winter half year

Pressure 1 day later   Winter half year

Pressure 2 days later   Winter half year
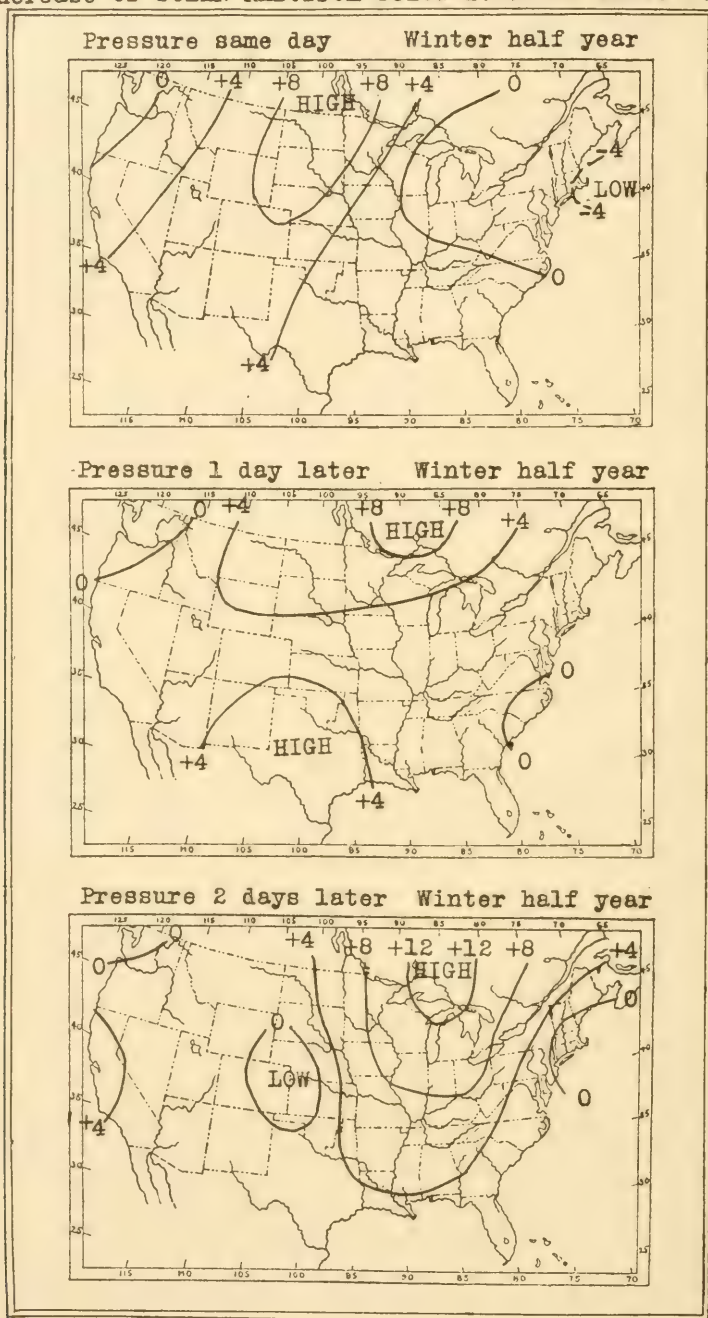
FIG. 5.—Mean pressure differences resulting from an increase of solar radiation from below 1.931 to above 1.960, 0 to 2 days later, winter half-year. Units in hundredths of an inch.

Increase of SOLAR RAD.from below 1.931 to above 1.960
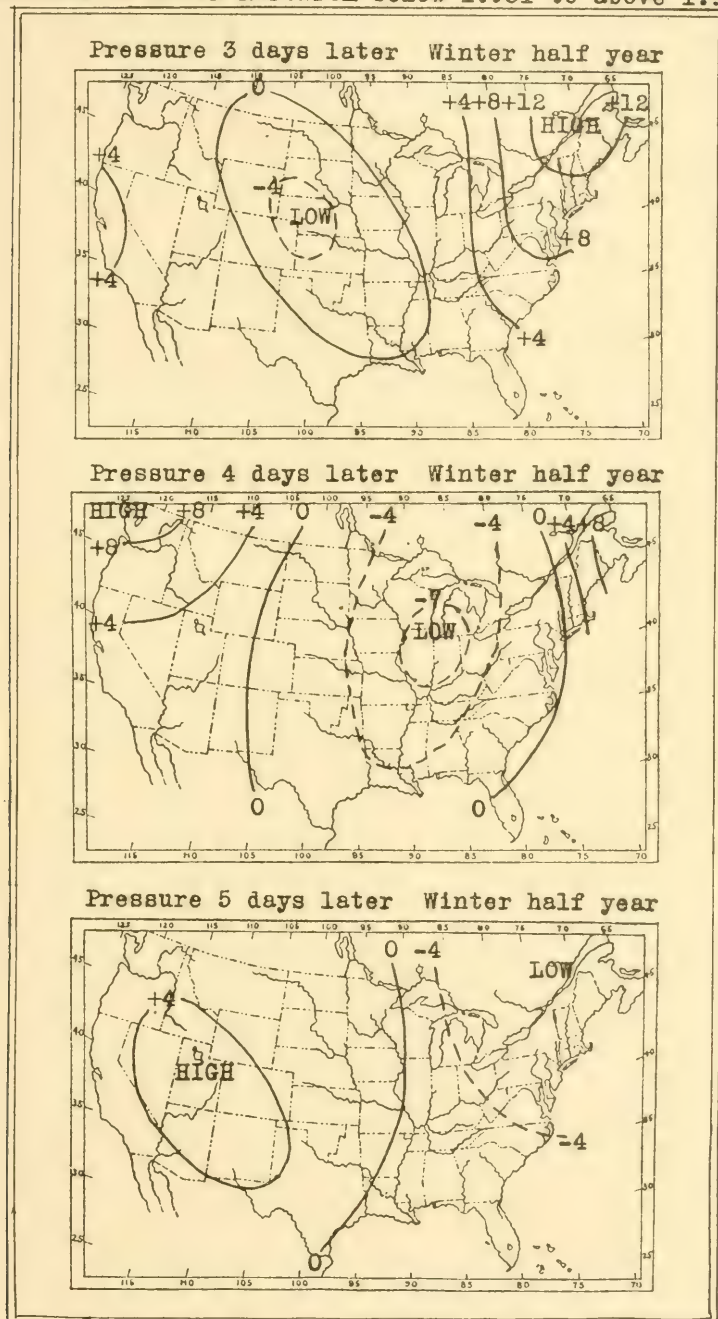
Fig. 6.—Mean pressure differences resulting from an increase in solar radiation from below 1.931 to above 1.960, 3 to 5 days later, winter half-year. Units in hundredths of an inch.

In summer, as shown by tables 4 and 5 and by the charts in figures 7 and 8, the high pressure forms farther north and drifts more slowly to the Atlantic coast, not reaching it until some six days or seven days later. In the case of the low pressure there does not appear any evident drift, but only an intensification in the permanent low pressure in the southwestern part of the United States accompanying an increase of solar radiation from low values to high values.

The next step in the investigation was to ascertain, if possible, whether the position of formation of the pressure maxima and minima were related to the absolute intensity of the solar radiation. For this purpose the observations of solar radiation were divided into grades of .010 calorie, running from 1.910 and below, to 1.981 and above. Taking the dates of the observations in each grade, the 8 a. m. pressures were averaged for 18 stations in the United States and Canada. The results are given in tables 6 and 7. The normal pressures for each station are also given in these tables. These are from 51-year means in the United States, but at the Canadian stations are from the means of the data used in our research. The departures from normal were plotted on maps of the United States for each day from zero day to three days later. Figures 9 and 10 give the departures of pressure for the day on which the solar observations were made (zero day). The upper chart in figure 9 shows the mean departures of pressure during the winter half-year accompanying very high values of solar radiation averaging about 2 per cent above normal, the middle chart shows pressure departures for solar radiation averaging about 1 per cent above normal, and the lower chart the pressure departures for solar radiation values averaging about 0.5 per cent above normal. It is seen that in each case there was a maximum of pressure in the Rocky Mountain region of the United States. In the case of the very high values of solar radiation, the maximum of pressure is in the extreme northwestern part of the United States and in Western Canada; in the case of medium intensity values of radiation, it is in the central Rocky Mountain region of the United States; and in the case of values slightly above normal, it is in the far southwest. In other words, there is a marked displacement of the center of high pressure southward with decreasing values of solar radiation approaching normal. With values of solar radiation below normal, a similar march of the area of low pressure was found. With very low values of solar radiation, low pressure is found over the western United States and central Canada, and as the intensity approaches normal the center of the low pressure area is displaced southward to the southern Rocky Mountain region.

TABLE 4.—*Mean Pressure for Each Day from Two Days Before to 12 Days Following Observed Solar-Radiation Values Above 1.960 Calories—Summer Half-Year.*

Station	Days Before		Days After														Normal
	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago	.019	.032	.026	.029	.038	.032	.050	.045	.030	.026	.040	.047	.044	.068	.002	.027
Father Point	.955	.956	.977	.966	.982	.949	.937	.959	.978	.979	.015	.986	.969	.971	.984	.967
Galveston	.990	.977	.981	.996	.004	.007	.003	.996	.991	.990	.992	.006	.000	.984	.986	.998
Hatteras	.026	.029	.032	.036	.041	.051	.040	.035	.030	.028	.031	.046	.022	.025	.025	.035
Jacksonville	.040	.026	.026	.037	.043	.041	.042	.037	.030	.028	.037	.042	.038	.035	.033	.044
Kamloops	.972	.970	.977	.964	.958	.957	.957	.937	.950	.967	.956	.950	.940	.922	.942	.958
Key West	.994	.985	.982	.994	.999	.994	.992	.991	.989	.991	.995	.995	.987	.985	.992	.003
Los Angeles	.922	.920	.923	.923	.924	.929	.924	.926	.920	.915	.918	.917	.928	.932	.925	.929
Memphis	.053	.036	.038	.048	.059	.061	.060	.048	.051	.047	.051	.063	.062	.040	.036	.054
New York	.002	.011	.031	.035	.021	.016	.024	.032	.030	.024	.027	.022	.019	.027	.035	.026
North Platte	.976	.964	.967	.007	.021	.008	.004	.008	.994	.981	.989	.988	.981	.969	.966	.994
Portland, Ore	.052	.051	.055	.050	.039	.032	.019	.024	.045	.045	.037	.030	.016	.027	.044	.045
Prince Albert	.933	.940	.984	.965	.923	.935	.961	.966	.923	.927	.935	.944	.941	.926	.914	.933
Roswell	.898	.899	.897	.913	.918	.916	.923	.891	.887	.889	.911	.923	.908	.906	.897	.912
Salt Lake	.882	.882	.896	.889	.903	.904	.888	.875	.868	.885	.878	.879	.868	.867	.883	.901
San Francisco	.963	.961	.966	.968	.964	.961	.950	.954	.964	.954	.952	.950	.953	.968	.960	.961
White River	.971	.998	.005	.997	.005	.972	.993	.006	.015	.019	.012	.996	.997	.002	.000	.993
Winnipeg	.977	.983	.012	.014	.984	.985	.003	.018	.979	.967	.986	.989	.985	.962	.962	.968

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

TABLE 5.—*Mean Pressure for Each Day from Two Days Before to 12 Days Following Observed Solar-Radiation Values Below 1.931 Calories—Summer Half-Year.*

Station	Days Before		Days After														Normal
	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago	.018	.020	.020	.020	.036	.020	.014	.016	.007	.005	.007	.007	.022	.031	.046	.027
Father Point	.981	.987	.969	.965	.957	.960	.959	.987	.953	.941	.939	.953	.961	.954	.975	.967
Galveston	.007	.007	.004	.999	.993	.996	.001	.007	.008	.007	.999	.003	.002	.004	.011	.998
Hatteras	.018	.062	.050	.040	.036	.041	.035	.036	.031	.022	.021	.025	.035	.042	.038	.035
Jacksonville	.055	.056	.055	.050	.049	.050	.055	.052	.054	.054	.050	.048	.050	.054	.051	.044
Kamloops	.969	.968	.960	.967	.961	.956	.950	.970	.964	.961	.943	.959	.966	.974	.971	.958
Key West	.015	.012	.014	.012	.011	.016	.020	.020	.018	.018	.018	.014	.010	.012	.009	.003
Los Angeles	.934	.935	.936	.928	.928	.930	.932	.932	.934	.939	.975	.931	.929	.933	.941	.929
Memphis	.067	.066	.062	.060	.053	.054	.055	.053	.058	.056	.054	.054	.056	.062	.074	.054
New York	.042	.053	.049	.011	.017	.030	.030	.020	.017	.011	.006	.018	.033	.040	.040	.026
North Platte	.008	.995	.997	.994	.000	.987	.991	.993	.005	.002	.004	.994	.997	.016	.028	.994
Portland, Ore	.054	.047	.038	.041	.037	.042	.054	.060	.059	.057	.050	.048	.067	.055	.064	.045
Prince Albert	.935	.924	.942	.933	.935	.941	.923	.931	.932	.922	.900	.900	.905	.919	.929	.933
Roswell	.918	.926	.921	.916	.913	.915	.913	.911	.917	.919	.926	.917	.905	.926	.938	.912
Salt Lake	.927	.923	.917	.909	.900	.907	.914	.950	.918	.915	.922	.912	.916	.923	.929	.901
San Francisco	.966	.966	.967	.959	.959	.963	.966	.962	.962	.967	.965	.957	.952	.954	.965	.961
White River	.988	.986	.984	.986	.990	.991	.990	.982	.970	.961	.982	.981	.999	.000	.002	.993
Winnipeg	.953	.943	.950	.952	.960	.960	.950	.958	.948	.959	.934	.932	.934	.943	.969	.968

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

Increase of SOLAR RAD. from below 1.931 to above 1.960
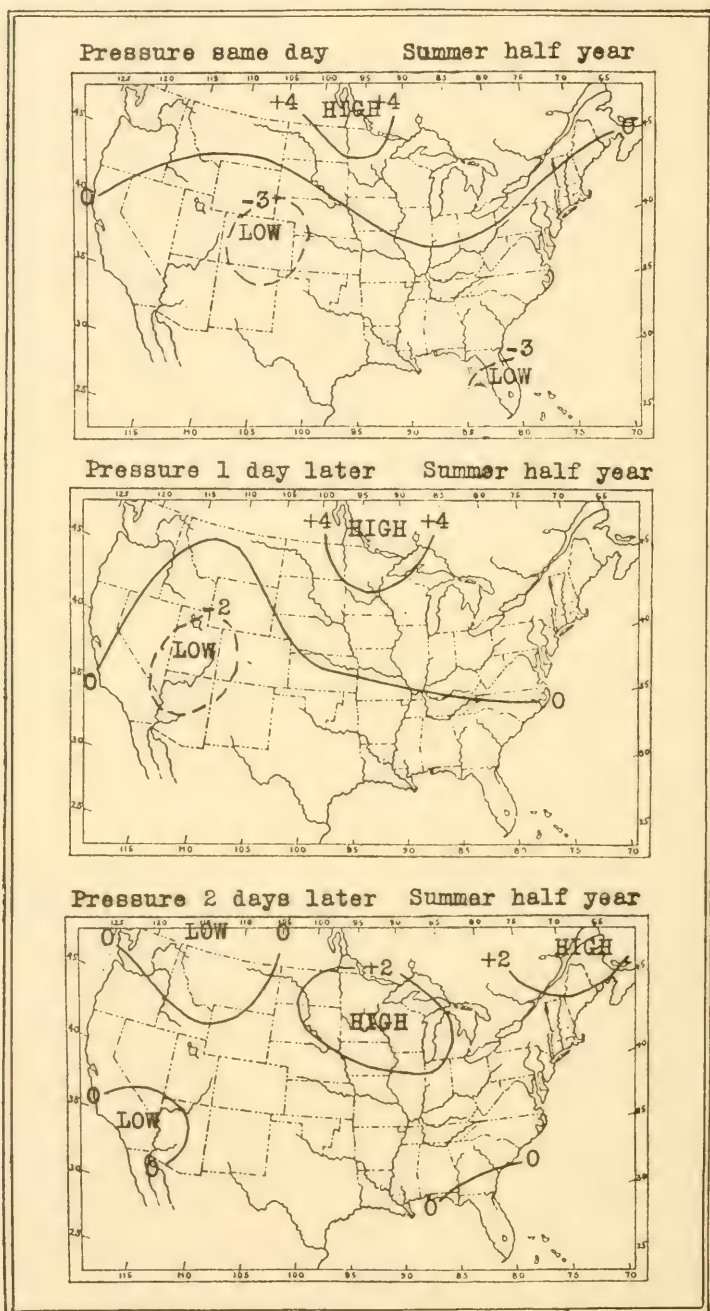
FIG. 7.—Mean pressure differences resulting from an increase in solar radiation from below 1.931 to above 1.960, 0 to 2 days later, summer half-year. Units in hundredths of an inch.

Increase of SOLAR RAD. from below 1.931 to above 1.960
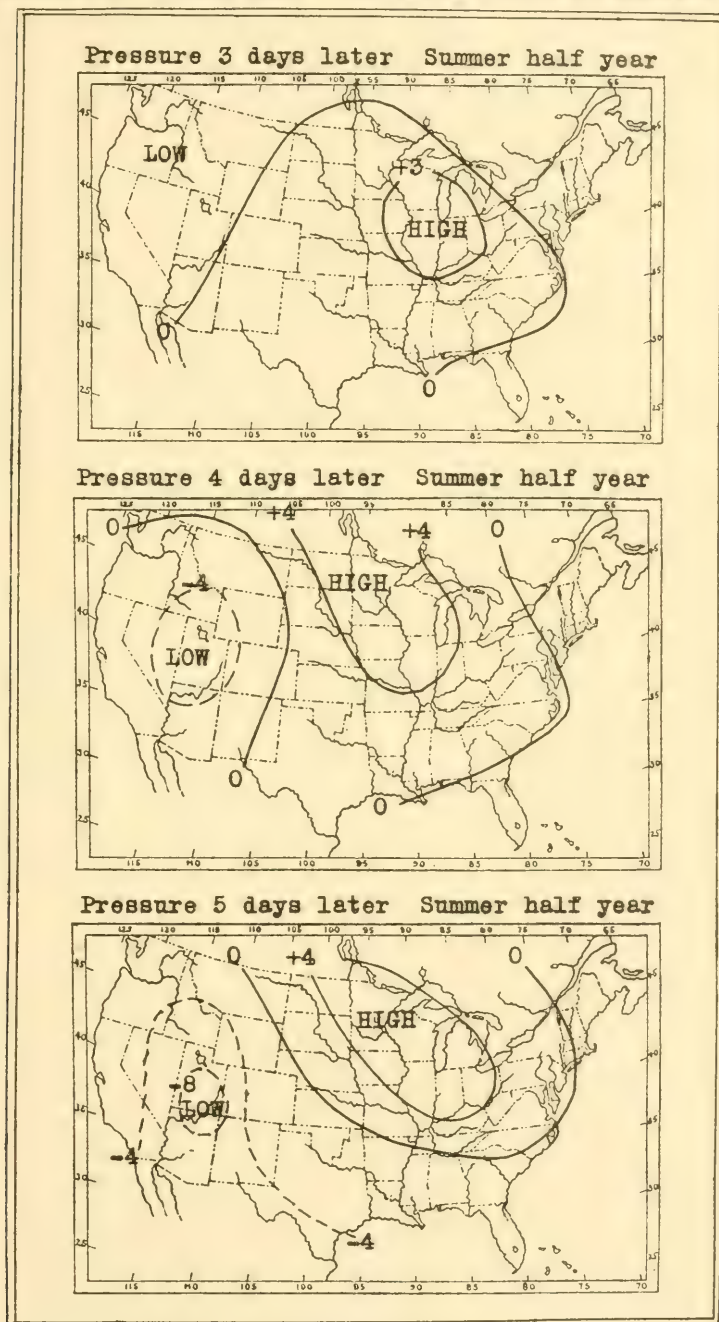
Fig. 8.—Mean pressure differences resulting from an increase in solar radiation from below 1.931 to above 1.960, 3 to 5 days later, summer half-year. Units in hundredths of an inch.

TABLE 6.—*Mean Pressure Following Different Intensities of Solar Radiation— Winter Half-Year.*

	Days After						Days After						Days After						Normal
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	
	1.981 and above No. of Cases 19						1.971 to 1.980 No. of Cases 18						1.961 to 1.970 No. of Cases 71						
Chicago	.08	.10	.14	.02	.99	.08	.09	.12	.12	.10	.02	.94	.00	.06	.09	.07	.05	.07	.09
Father Point	.96	.04	.00	.16	.03	.98	.02	.11	.22	.12	.14	.05	.94	.92	.95	.05	.06	.01	.96
Galveston	.10	.16	.14	.12	.11	.07	.13	.06	.08	.07	.04	.11	.08	.11	.11	.10	.10	.09	.11
Hatteras	.09	.07	.04	.13	.06	.09	.07	.13	.21	.15	.08	.10	.08	.06	.11	.14	.10	.11	.12
Jacksonville	.15	.10	.12	.14	.12	.12	.14	.15	.16	.12	.09	.10	.11	.11	.13	.14	.12	.14	.13
Kamloops	.18	.12	.02	.06	.04	.03	.96	.97	.00	.16	.12	.04	.03	.99	.00	.97	.06	.05	.01
Key West	.09	.06	.06	.09	.09	.06	.04	.04	.03	.01	.03		.06	.06	.07	.08	.07	.07	.06
Los Angeles	.03	.09	.05	.03	.07	.09	.03	.01	.05	.04	.05	.05	.07	.05	.04	.04	.02	.04	.04
Memphis	.17	.16	.20	.13	.15	.10	.20	.14	.14	.14	.11	.11	.10	.14	.17	.13	.15	.16	.17
New York	.08	.05	.03	.18	.01	.03	.05	.14	.21	.20	.12	.08	.07	.08	.10	.18	.12	.14	.08
North Platte	.23	.21	.10	.03	.13	.09	.16	.97	.15	.14	.16	.12	.13	.14	.09	.10	.07	.12	.13
Portland, Ore	.17	.10	.12	.08	.12	.17	.00	.06	.02	.15	.13	.04	.08	.08	.05	.01	.08	.09	.06
Prince Albert	.05	.04	.80	.90	.99	.95	.98	.02	.10	.13	.15	.07	.00	.00	.99	.00	.99	.00	.04
Roswell	.10	.15	.11	.10	.04	.12	.06	.98	.00	.98	.05	.11	.05	.07	.02	.04	.04	.02	.06
Salt Lake	.17	.17	.13	.22	.12	.18	.00	.00	.04	.04	.10	.13	.14	.11	.08	.04	.06	.08	.10
San Francisco	.10	.11	.10	.09	.16	.09	.03	.08	.08	.12	.09	.06	.12	.10	.07	.07	.08	.07	.08
White River	.96	.04	.06	.93	.94	.03	.08	.07	.04	.07	.02	.92	.92	.99	.04	.99	.97	.96	.02
Winnipeg	.07	.09	.96	.89	.00	.04	.11	.01	.15	.18	.16	.06	.04	.04	.03	.06	.99	.05	.08

	1.951 to 1.960 No. of Cases 127						1.941 to 1.950 No. of Cases 114						1.931 to 1.940 No. of Cases 64						Normal
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	
Chicago	.07	.05	.09	.09	.07	.09	.08	.09	.06	.10	.12	.10	.11	.08	.09	.06	.09	.13	.09
Father Point	.01	.03	.99	.98	.01	.02	.99	.01	.04	.01	.00	.03	.98	.01	.98	.02	.99	.00	.96
Galveston	.11	.11	.13	.11	.10	.12	.12	.09	.08	.09	.10	.09	.09	.10	.08	.07	.10	.13	.11
Hatteras	.09	.11	.10	.11	.12	.11	.12	.15	.11	.09	.12	.11	.11	.08	.10	.10	.07	.09	.12
Jacksonville	.12	.13	.12	.13	.13	.13	.15	.15	.12	.11	.13	.11	.11	.10	.12	.10	.08	.12	.13
Kamloops	.04	.06	.03	.04	.06	.06	.01	.03	.10	.09	.05	.05	.06	.04	.02	.02	.96	.96	.01
Key West	.05	.06	.06	.06	.06	.09	.09	.09	.09	.08	.09	.09	.04	.03	.04	.03	.03	.05	.06
Los Angeles	.04	.04	.03	.02	.02	.04	.05	.04	.03	.02	.04	.04	.04	.03	.02	.02	.03	.02	.04
Memphis	15	15	19	17	15	17	18	16	14	15	16	16	15	13	12	12	12	17	.17
New York	.04	.07	.04	.05	.09	.07	.10	.14	.11	.10	.10	.13	.09	.10	.08	.07	.07	.07	.08
North Platte	.10	.14	.16	.12	.12	.14	.11	.10	.11	.14	.13	.09	.10	.10	.12	.10	.13	.08	.13
Portland, Ore	.06	.06	.06	.06	.06	.09	.06	.09	.11	.12	.09	.08	.11	.08	.08	.08	.02	.04	.06
Prince Albert	.01	.02	.01	.99	.03	.03	.00	.99	.04	.05	.04	.98	.97	.00	.01	.98	.97	.98	.04
Roswell	.06	.07	.08	.05	.03	.05	.04	.03	.03	.05	.04	.04	.04	.02	.03	.03	.06	.03	.06
Salt Lake	.08	.09	.07	.05	.03	.06	.10	.08	.08	.09	.09	.10	.09	.10	.09	.08	.09	.03	.10
San Francisco	.07	.07	.06	.05	.05	.06	.09	.09	.09	.08	.09	.08	.10	.09	.08	.07	.05	.05	.08
White River	.97	.96	.95	.97	.98	.00	.99	.02	.01	.01	.05	.04	.01	.97	.00	.01	.00	.05	.02
Winnipeg	.05	.05	.04	.03	.07	.08	.05	.03	.05	.10	.09	.06	.01	.00	.06	.02	.05	.00	.08

	1.921 to 1.930 No. of Cases 41						1.911 to 1.920 No. of Cases 19						1.910 and below No. of Cases 19						Normal
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	
Chicago	.05	.05	.02	.04	.11	.09	.98	.03	.00	.03	.08	.03	.10	.06	.01	.08	.12	.09	....
Father Point	.97	.95	.96	.93	.91	.00	.85	.86	.91	.00	.11	.13	.12	.06	.99	.92	.06	.19	....
Galveston	.05	.03	.07	.12	.14	.09	.04	.07	.05	.05	.08	.07	.10	.09	.11	.10	.09	.09	....
Hatteras	08	07	08	10	.15	.13	.07	08	.10	06	.11	11	17	16	10	08	21	20	....
Jacksonville	10	10	10	13	15	16	06	09	09	08	09	09	16	13	11	10	14	11	....
Kamloops	.08	.02	.02	.04	.02	.11	.99	.98	.99	.01	.87	.95	.04	.07	.01	.95	.03	.10	....
Key West	.04	.04	.04	.05	.06	.06	.02	.03	.02	.02	.04	.05	.06	.05	.04	.03	.05	.04	....
Los Angeles	.01	.01	.01	.04	.04	.04	.02	.03	.03	.99	.03	.00	.99	.03	.03	.02	.02	.03	....
Memphis	.13	.11	.12	.17	22	.16	.06	.13	.08	.06	.10	12	.15	.15	.15	.21	.21	.17	....
New York	.08	.02	.10	.04	.08	.16	.03	.99	.07	.05	.09	.08	.18	.15	.07	.04	.15	.10	....
North Platte	.11	.13	.08	.09	.10	.10	.07	.06	.99	.09	.02	.97	.09	.14	.10	.13	.05	.15	....
Portland, Ore	.10	.06	.05	.06	.07	.08	.08	.06	.99	.97	.89	.00	.10	.04	.01	.99	.06	.09	....
Prince Albert	.92	.91	.90	.02	.02	.02	.02	.98	.02	.99	.00	.95	.95	.97	.01	.06	.98	.98	....
Roswell	.02	.03	.04	.05	.06	.03	.96	.99	.94	.97	.00	.93	.05	.06	.03	.06	.03	.05	....
Salt Lake	.10	.09	.08	.09	.07	.10	.04	.04	.05	.00	.95	.91	.07	.08	.05	.04	.06	.13	....
San Francisco	.06	.05	.03	.04	.08	.08	.08	.06	.04	.98	.98	.03	.05	.04	.04	.03	.08	.11	....
White River	.97	.92	.90	.92	.97	.03	.92	.95	.99	.01	.04	.00	.96	.94	.89	.10	.12	.97	....
Winnipeg	.92	.97	.97	.97	.06	.06	.00	.03	.98	.03	.07	.92	.93	.02	.02	.10	.01	.04	....

NOTE: When the first figures in the table are .8 or .9, add 29 inches; when they are .0, .1 or .2, add 30 inches.

TABLE 7.—*Mean Pressure Following Different Intensities of Solar Radiation—Summer Half-Year.*

	Days After						Days After						Days After						Nor-mal
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	
	1.981 and above No. of Cases 15						1.971 to 1.980 No. of Cases 19						1.961 to 1.970 No. of Cases 61						
Chicago	.06	.07	.05	.09	.13	.07	.06	.02	.03	.04	.06	.07	.01	.02	.04	.01	.02	.03	.02
Father Point	.07	.06	.06	.97	.95	.99	.89	.94	.02	.01	.01	.98	.98	.95	.95	.92	.91	.95	.94
Galveston	.96	.97	.97	.96	.94	.93	.97	.97	.99	.00	.00	.01	.97	.99	.00	.01	.00	.99	.00
Hatteras	.09	.10	.07	.08	.08	.09	.01	.04	.04	.06	.02	.05	.02	.02	.04	.04	.04	.02	.04
Jacksonville	.06	.06	.06	.04	.05	.05	.03	.03	.04	.02	.03	.04	.02	.03	.04	.04	.05	.03	.04
Kamloops	.03	.01	.01	.06	.01	.96	.96	.98	.95	.99	.00	.96	.97	.95	.95	.92	.93	.92	.95
Key West	.00	.01	.00	.01	.00	.99	.99	.00	.00	.00	.00	.01	.98	.99	.00	.99	.99	.99	.00
Los Angeles	.93	.92	.93	.92	.92	.93	.91	.91	.92	.93	.91	.90	.93	.93	.93	.93	.93	.93	.93
Memphis	.10	.10	.11	.11	.10	.06	.03	.02	.04	.05	.03	.07	.02	.04	.05	.05	.06	.04	.05
New York	.10	.12	.10	.05	.08	.09	.99	.03	.04	.03	.03	.06	.03	.01	.99	.00	.00	.01	.02
North Platte	.94	.03	.11	.08	.04	.05	.93	.97	.05	.04	.04	.99	.99	.01	.98	.98	.98	.00	.99
Portland, Ore.	.08	.11	.10	.04	.00	.03	.06	.04	.05	.05	.06	.02	.05	.05	.04	.02	.01	.03	.05
Prince Albert	.97	.04	.99	.00	.09	.08	.92	.96	.92	.92	.90	.95	.01	.95	.91	.92	.95	.94	.92
Roswell	.93	.93	.95	.94	.95	.95	.91	.89	.90	.95	.94	.94	.87	.90	.90	.89	.89	.85	.92
Salt Lake	.93	.92	.92	.92	.90	.90	.87	.88	.88	.94	.94	.90	.90	.88	.90	.89	.87	.86	.90
San Francisco	.98	.98	.99	.96	.96	.98	.94	.94	.96	.96	.93	.92	.97	.97	.96	.96	.95	.96	.96
White River	.08	.05	.07	.05	.05	.04	.00	.03	.04	.05	.04	.01	.00	.99	.99	.94	.98	.02	.98
Winnipeg	.02	.01	.99	.99	.98	.09	.96	.02	.99	.00	.97	.95	.01	.00	.96	.96	.00	.00	.96

	Days After						Days After						Days After					
	1.951 to 1.960 No. of Cases 108						1.941 to 1.950 No. of Cases 135						1.931 to 1.940 No. of Cases 116					
Chicago	.98	.01	.01	.01	.02	.02	.04	.02	.00	.01	.01	.01	.02	.02	.01	.01	.01	.00
Father Point	.92	.94	.96	.96	.93	.96	.95	.95	.93	.92	.94	.94	.96	.97	.95	.98	.98	.95
Galveston	.97	.97	.97	.99	.99	.00	.01	.01	.02	.01	.00	.00	.99	.99	.00	.99	.00	.99
Hatteras	.03	.01	.02	.02	.02	.03	.01	.02	.02	.01	.03	.03	.02	.05	.04	.04	.03	.03
Jacksonville	.03	.03	.03	.03	.04	.04	.04	.04	.04	.04	.04	.05	.04	.05	.06	.05	.03	.03
Kamloops	.96	.96	.95	.96	.94	.97	.96	.95	.97	.96	.95	.95	.96	.95	.96	.98	.99	.97
Key West	.99	.98	.98	.99	.99	.99	.96	.97	.97	.96	.96	.97	.99	.00	.01	.00	.99	.00
Los Angeles	.91	.92	.92	.92	.92	.93	.93	.94	.94	.93	.93	.93	.93	.93	.93	.93	.93	.93
Memphis	.04	.03	.03	.04	.05	.05	.06	.06	.06	.06	.06	.06	.05	.05	.06	.05	.04	.04
New York	.01	.01	.04	.03	.03	.05	.00	.02	.01	.01	.01	.02	.04	.04	.03	.02	.01	.02
North Platte	.97	.98	.98	.97	.98	.97	.99	.00	.99	.00	.00	.99	.97	.96	.97	.99	.99	.01
Portland, Ore.	.05	.05	.02	.03	.05	.04	.05	.05	.06	.04	.03	.04	.05	.05	.06	.06	.06	.04
Prince Albert	.94	.95	.94	.94	.95	.95	.90	.89	.91	.91	.90	.89	.90	.92	.94	.93	.93	.92
Roswell	.89	.89	.90	.89	.90	.91	.92	.92	.92	.92	.92	.92	.89	.90	.91	.91	.91	.91
Salt Lake	.87	.88	.87	.87	.88	.89	.91	.92	.92	.91	.91	.91	.90	.91	.92	.92	.92	.92
San Francisco	.95	.95	.96	.96	.97	.97	.96	.97	.97	.96	.96	.97	.98	.97	.98	.98	.97	.96
White River	.94	.97	.97	.97	.99	.99	.99	.95	.93	.94	.94	.95	.96	.96	.98	.97	.97	.95
Winnipeg	.96	.98	.97	.99	.98	.98	.96	.93	.94	.92	.95	.94	.92	.93	.94	.97	.96	.95

	Days After						Days After						Days After					
	1.921 to 1.930 No. of Cases 76						1.911 to 1.920 No. of Cases 46						1.910 and below No. of Cases 50					
Chicago	.00	.00	.00	.02	.99	.99	.02	.03	.02	.04	.06	.06	.05	.04	.04	.00	.01	.02
Father Point	.92	.91	.95	.94	.98	.98	.02	.00	.94	.96	.98	.98	.00	.02	.98	.98	.92	.01
Galveston	.01	.01	.01	.00	.99	.00	.01	.99	.97	.00	.02	.02	.99	.99	.99	.99	.01	.01
Hatteras	.08	.05	.03	.03	.03	.03	.03	.05	.07	.06	.04	.05	.03	.02	.02	.03	.03	.04
Jacksonville	.08	.06	.05	.05	.05	.05	.05	.10	.07	.08	.05	.03	.02	.02	.03	.04	.05	.04
Kamloops	.98	.97	.95	.97	.97	.98	.91	.95	.96	.94	.93	.93	.98	.97	.98	.95	.93	.98
Key West	.03	.02	.01	.02	.02	.02	.01	.01	.02	.03	.04	.03	.00	.00	.00	.00	.01	.01
Los Angeles	.95	.93	.94	.94	.94	.93	.93	.93	.93	.94	.93	.92	.92	.92	.91	.91	.92	.92
Memphis	.07	.07	.05	.04	.04	.04	.07	.07	.06	.08	.08	.07	.04	.04	.05	.05	.05	.05
New York	.06	.99	.01	.02	.02	.02	.04	.03	.04	.01	.04	.04	.05	.04	.02	.06	.04	.07
North Platte	.92	.00	.00	.96	.98	.00	.01	.97	.04	.05	.02	.00	.00	.02	.99	.00	.00	.00
Portland, Ore.	.06	.04	.02	.05	.07	.06	.02	.07	.05	.04	.03	.06	.02	.02	.05	.03	.05	.07
Prince Albert	.94	.94	.95	.94	.94	.94	.91	.91	.94	.95	.92	.94	.97	.94	.91	.94	.89	.90
Roswell	.90	.82	.91	.89	.89	.90	.93	.89	.90	.95	.94	.92	.93	.93	.92	.92	.92	.93
Salt Lake	.92	.90	.89	.89	.90	.92	.92	.92	.93	.93	.92	.92	.91	.91	.89	.91	.93	.94
San Francisco	.98	.96	.96	.97	.97	.97	.96	.97	.96	.96	.97	.97	.95	.95	.95	.95	.96	.95
White River	.96	.97	.97	.99	.95	.96	.96	.98	.00	.00	.03	.00	.04	.02	.02	.97	.01	.00
Winnipeg	.94	.96	.96	.97	.94	.99	.95	.93	.98	.98	.98	.95	.99	.98	.95	.95	.96	.93

NOTE: When the first figures in the table are .8 or .9, add 29 inches; when they are .0 or .1, add 30 inches.

Fig. 9.—Mean pressure deviations from normal following differ-
ent intensities of solar radiation in steps above 1.950, winter half-
year. Units in hundredths of an inch. Same day.

Solar Radiation below 1.911 (2% below normal)
Pressure same day   Winter half year

Solar Radiation 1.921-30 (1% below normal)
Pressure same day   Winter half year

Solar Radiation 1.931-40 (0.5% below normal)
Pressure same day   Winter half year

FIG. 10.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. Same day.

2

Fig. 11.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. One day later.

Solar Radiation below 1.911 (2% below normal)
Pressure 1 day later   Winter half year

Solar Radiation 1.921-30 (1% below normal)
Pressure 1 day later   Winter half year

Solar Radiation 1.931-40 (0.5% below normal)
Pressure 1 day later   Winter half year

FIG. 12.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. One day later.

The succeeding maps show that the areas of high and low pressure thus formed in the western United States drift eastward and pass off the eastern coast three days later. It is worthy of note that on the day of the solar observation the high pressure accompanying high values of solar radiation is found in the Rocky Mountain region further west than the low pressure accompanying low values of solar radiation, but as the areas of high and low pressure drift eastward on subsequent days, the two come more nearly in opposition, so that on the second and third days following the solar data (see figs. 13 to 16), the areas of high and low pressure on the maps following high solar radiation are almost in exact opposition to the high and low pressure areas following low solar radiation for the same amounts of departure from normal radiation. Whether the differences in position found in the Rocky Mountain region on the day of the solar observations are real differences, or merely due to variations arising from other causes not eliminated in the means, remains for the future to determine.

In figures 17 and 18 are shown the mean departures from normal pressure accompanying different intensities of solar radiation in the summer half-year on the day of the solar observation. In general, there is an intensification of the normal low pressure area in the southern Rocky Mountain Plateau with high values of solar radiation, and an increased pressure in the northern United States and in southern Canada. With low values of solar radiation the tendency is for the pressure to fall in the central and northern parts of the United States and to rise in the south and east. This result is not evident, however, in the case of the mean values below 1.911 calories, probably because of a lack of a sufficient number of observations.

The charts for the succeeding days are not reproduced, but the mean pressures are given in table 7 and can easily be plotted by anyone wishing to study them.

Fig. 13.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. Two days later.

FIG. 14.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. Two days later.

FIG. 15.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. Three days later.

Solar Radiation below 1.911 (2% below normal)
Pressure 3 days later   Winter half year
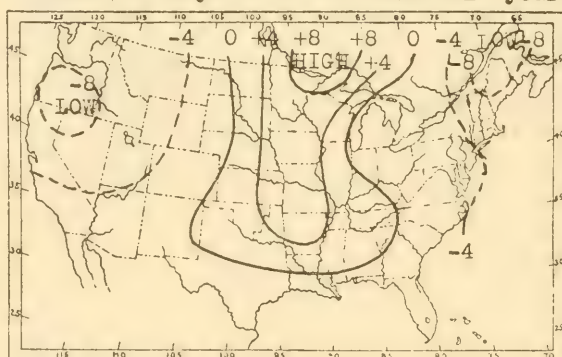
Solar Radiation 1.921-30 (1% below normal)
Pressure 3 days later   Winter half year
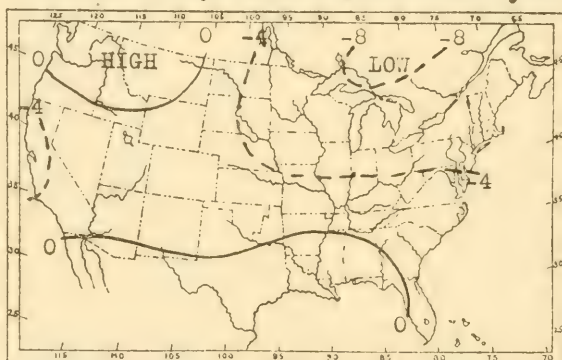
Solar Radiation 1.931-40 (0.5% below normal)
Pressure 3 days later   Winter half year
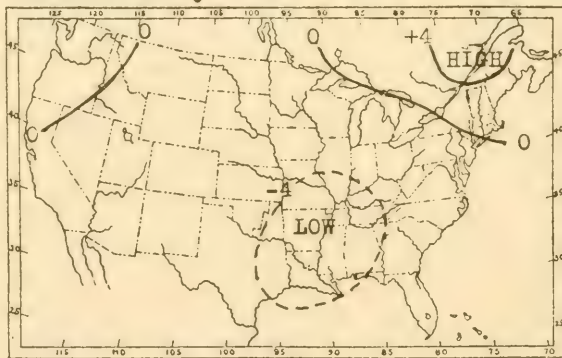
FIG. 16.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. Three days later.

Solar Radiation above 1.980 (2% above normal)
Pressure same day   Summer half year
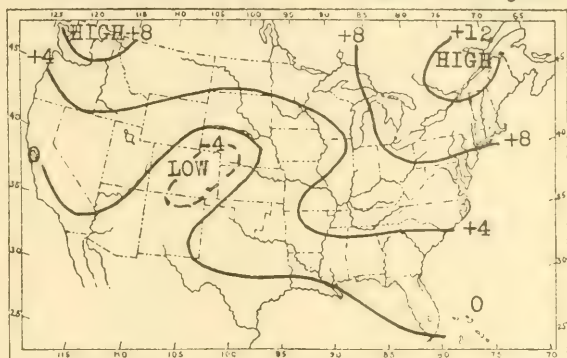
Solar Radiation 1.961-70 (1% above normal)
Pressure same day   Summer half year
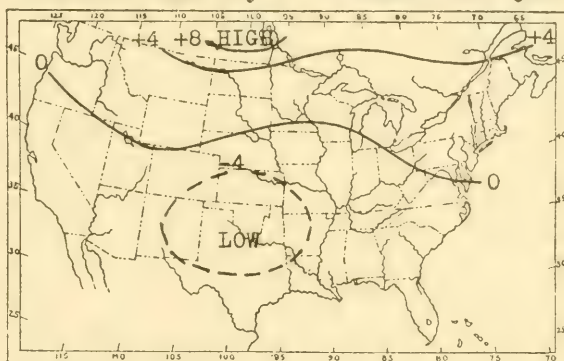
Solar Radiation 1.951-60 (0.5% above normal)
Pressure same day   Summer half year
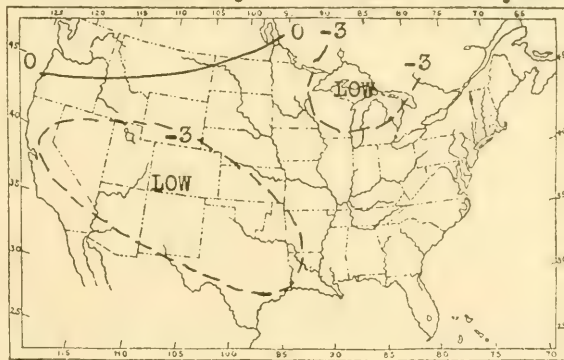
Fig. 17.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, summer half-year. Units in hundredths of an inch. Same day.
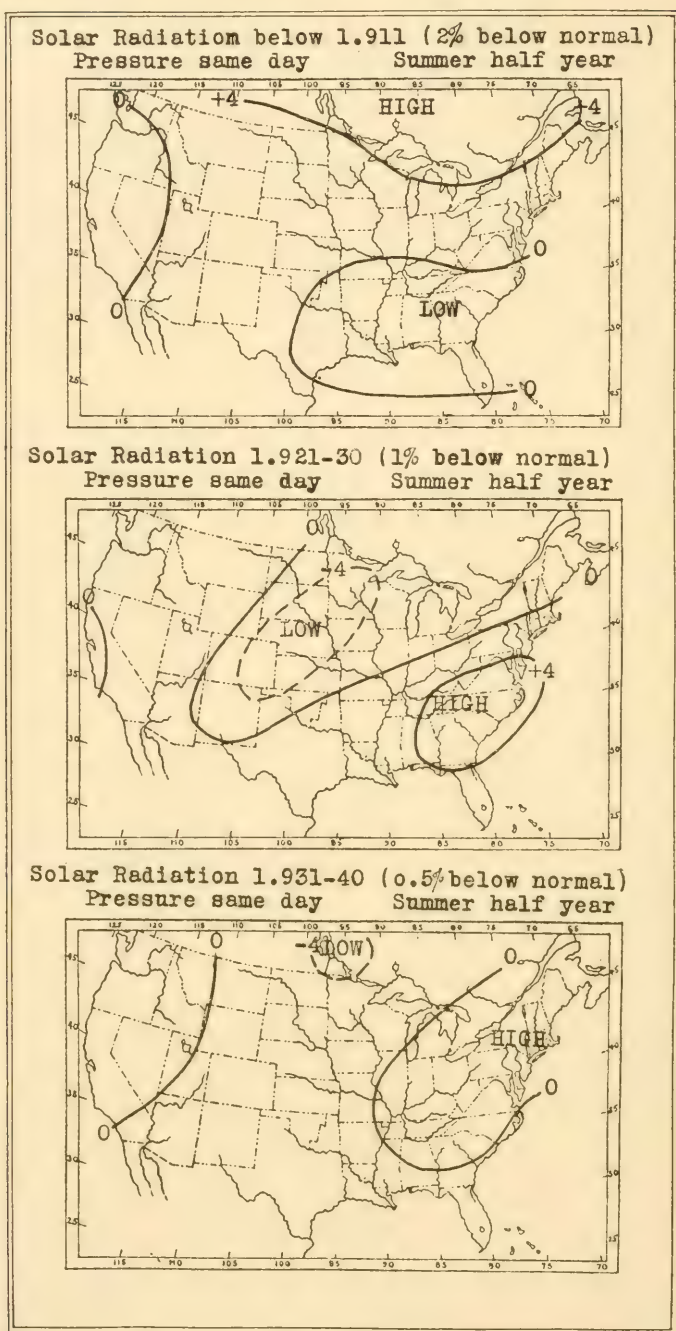
FIG. 18.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, summer half-year. Units in hundredths of an inch. Same day.

In table 8 are given the mean maximum temperatures at Winnipeg and New York for the interval from two days preceding to twelve days following observed high and low solar radiation values, between July, 1918, and September, 1922, inclusive, for the winter and summer half-years separately. At the bottom of this table is given the dif-

TABLE 8.—*Mean of the Daily Maximum of Temperature from Two Days Before to 12 Days Following Observed Solar-Radiation Values, Temperature Means Given in Degrees and Tenths Fahrenheit.*

Days	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	12	Normal
Solar radiation below 1.931—Winter half-year.																
Winnipeg...	32.1	30.7	32.4	30.2	30.3	29.7	29.5	29.9	28.4	30.2	28.8	27.4	27.8	28.0	28.1	25.7
New York..	51.5	52.0	52.3	52.6	52.0	52.1	50.9	49.7	49.5	51.1	49.7	50.9	51.7	50.0	50.2	48.6
Solar radiation above 1.960—Winter half-year																
Winnipeg ..	23.1	22.5	20.9	21.4	22.2	22.7	23.1	21.8	22.4	21.2	21.0	22.2	20.8	21.2	20.9	25.7
New York..	47.1	47.1	47.9	46.5	45.4	45.1	46.1	46.1	45.7	45.8	46.5	45.6	45.2	46.0	45.2	48.6
Solar radiation below 1.931—Summer half-year																
Winnipeg...	71.4	71.0	71.1	71.1	71.4	71.8	72.2	71.8	71.2	71.0	71.8	71.9	72.1	72.5	72.3	69.9
New York..	74.6	74.7	74.9	74.9	74.6	75.0	75.0	75.1	74.9	74.4	74.4	74.6	75.2	75.6	75.1	73.5
Solar radiation above 1.960—Summer half-year.																
Winnipeg...	68.6	67.4	66.9	67.3	68.0	67.0	66.8	67.4	68.9	68.1	68.6	69.2	68.2	69.7	70.5	69.9
New York..	70.9	72.0	71.7	72.7	72.0	72.8	72.4	71.7	72.3	72.5	72.0	72.0	72.7	71.6	72.4	73.5
Differences between values below 1.931 and above 1.960—Winter half-year.																
Winnipeg...	+9.0	+8.2	+11.5	+8.8	+8.1	+7.0	+6.4	+8.1	+6.0	+9.0	+7.8	+5.2	+7.0	+6.8	+7.2	....
New York..	+4.4	+4.9	+4.4	+6.1	+6.6	+7.0	+4.8	+3.6	+3.8	+5.3	+3.2	+4.3	+6.5	+4.0	+5.0	....
Summer half-year																
Winnipeg...	+2.8	+3.6	+4.2	+3.8	+3.4	+4.8	+5.4	+4.4	+2.3	+2.9	+3.2	+2.7	+3.9	+2.8	+1.8	....
New York..	+3.7	+2.7	+3.2	+2.2	+2.6	+2.2	+2.6	+3.4	+2.6	+1.9	+2.4	+2.6	+2.5	+4.0	+2.7	....

ference between the mean temperatures with low solar radiation and that with high solar radiation. These results are plotted for the winter months in figure 19. It is seen from the table that at Winnipeg and New York, it is warmer both in winter and in summer with low solar radiation than with high solar radiation. The maximum difference in winter at Winnipeg is 11.5° F. This is a very large difference, showing that even a moderate increase of solar radiation may bring

a large change of temperature in middle latitudes. The maximum occurs on zero day, that is, on the day of the solar observation, while at New York the maximum difference is 7° F. three days after the solar observation, showing that the temperature changes like the pressure changes move from the interior of the continent to the eastern coast. It should be noted, however, that atmospheric pressure is found highest with high solar radiation, while the highest temperature is found with low solar radiation, the two being inverted
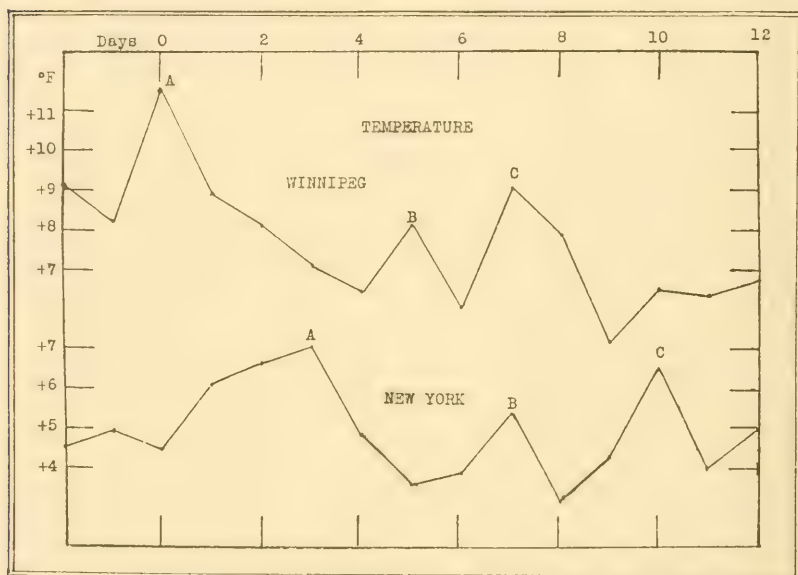
FIG. 19.—Differences between mean temperatures with low and high solar radiation, winter half-year, 1918-1922.

to each other, and showing secondary maxima and minima at the same intervals apart. The range from the maximum difference at Winnipeg at zero day to a minimum difference at four days is 5.1° F., while at New York the range from a maximum difference at three days to a minimum difference at five days is 3.4° F. In summer the maximum differences at Winnipeg and New York came several days later than in winter.

The observations of the Astrophysical Observatory show not only that the solar heat radiation varies materially from day to day, but also show that the monthly mean values vary at times as much as 2 per cent from the normal.

The monthly means are given in table 9, and include all the months during which observations have been obtained since the beginning of observations on Mount Wilson in 1905. They are made up from observations at Mt. Wilson and at Calama, Chile, in 1918; from Calama alone from October, 1919, to September, 1920; and after October, 1920, from simultaneous observations at Montezuma, Chile, and Mt. Harqua Hala, Arizona.

In order to study the effects of the changes in the monthly means of solar radiation on the weather of the world, the months of

TABLE 9.—*Monthly and Annual Means of Observed Values of Solar Radiation in Calories Per Sq. Cm. Per Minute. Made by The Astrophysical Observatory of the Smithsonian Institution.*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1905						1.968	1.972	1.955	1.930	1.928			1.951
1906					1.947	1.940	1.962	1.943	1.948	1.918			1.943
1907													
1908					1.934	1.944	1.935	1.951	1.938	1.951	1.961		1.945
1909						1.930	1.911	1.926	1.908	1.889	1.933		1.914
1910					1.916	1.933	1.913	1.912	1.915	1.927	1.927		1.920
1911						1.945	1.917	1.929	1.938	1.915	1.903		1.926
1912					1.942	1.930	1.950	1.957	1.962				1.946
1913						1.928	1.940	1.918	1.866	1.866			1.903
1914						1.954	1.959	1.966	1.945	1.951			1.956
1915						1.942	1.947	1.951	1.968	1.950			1.952
1916						1.949	1.947	1.952	1.942	1.937			1.946
1917							1.989	1.956	1.948	1.952			1.959
1918						1.943	1.954	1.954	1.944	1.934	1.911	1.959	1.946
1919	1.943	1.949	1.941	1.951	1.940	1.955	1.954	1.953	1.939	1.952	1.953	1.952	1.948
1920	1.964	1.956	1.946	1.952	1.953	1.939	1.945	1.930	1.942	1.943	1.948	1.955	1.948
1921	1.958	1.951	1.946	1.947	1.950	1.934	1.945	1.937	1.944	1.945	1.954	1.050	1.947
1922	1.945	1.945	1.934	1.927	1.926	1.919	1.911	1.918	1.904	1.919	1.921	1.925	1.924
1923	1.923	1.918	1.913	1.914	1.920	1.918	1.926	1.931	1.933	1.931	1.929	1.923	1.923
1924	1.927	1.919	1.918	1.916	1.922	1.923	1.922	1.921	1.920	1.931	1.931	1.931	1.923

January and July were selected as representing opposite seasonal conditions. Departures from the normal pressure, temperature, and precipitation were taken as being the best means of studying the influence of the solar changes. There are only five Januaries available for study. The mean solar radiation of January, 1919, was normal, that of 1920 was 1 per cent above normal, and that of 1923 was 1 per cent below normal. Data for these months were available for study partly because I had already contrasted January, 1920, with January, 1919.[1]

The data for 1923 were obtained from the Canadian, United States, and Mexican weather services. By adding February, 1920, a winter

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[1] See "Boletín mensual de la Oficina Meteorológica Nacional," Buenos Aires, 1919, published in 1922.

month is obtained with solar radiation 0.5 per cent above normal. In this way there is formed a series showing the positions of the areas of departures from normal with different intensities of solar radiation of 0.5 per cent running from 1 per cent above to 1 per cent below normal, with only one step missing. Figure 20 shows the departures of pressure from normal over the North American continent in January, 1920, when the solar radiation was 1 per cent above normal. It is seen that a marked excess of pressure is found in Alaska and northern Canada, with the maximum departures near the 60th parallel of latitude. In February (see fig. 22) with a decrease of 0.5 per cent in the mean solar radiation, the excess of pressure is displaced southward and the maximum is found near the latitude of 52° N. In January, 1919 (see fig. 24), the solar radiation was normal or 0.5 per cent lower than in February, 1920, and the maximum excess of pressure is found in the Rocky Mountain region near the latitude of 40° N. This is near the normal position of the high pressure area in the United States which is thus shown to be intensified when the solar radiation is normal, as is also the low pressure which is found in the vicinity of Alaska. Figure 26 shows the distribution of pressure in January, 1923, when the solar radiation was 1 per cent below normal. The excess of pressure is now displaced southward to near the latitude of 30° N., and a defect of pressure covers the larger part of the United States and Alaska, so that the distribution is nearly opposite to that in January, 1920, when the solar radiation was 1 per cent above normal. It should be noted also that the greatest defect of pressure in Canada is displaced southward of its position in 1919 some 10° or more.

The departures of temperature from normal are found closely related to the departures of pressure and change their positions in unison with them. By comparing the charts of pressure and of temperature departures, figures 20 to 27, it is seen that the warm areas are north of the maximum excess of pressure and south of the maximum defect of pressure, while the areas of cold are south or southeast of the areas of excess pressure and north or west of the areas of deficient pressure.

Figure 21 shows the departures from normal temperature in North America in January, 1920, when the solar radiation averaged 1 per cent above normal. An area of cold covers all of Canada and a large part of the United States with the area of greatest departure in the St. Lawrence Valley, where the temperature averages from 9° F. to 13° F. below normal. There was an area of slight excess in

the Rocky Mountains and Pacific Coast. If observations had been available from the extreme north, an area of marked excess would probably have been found in the Arctic region north of Alaska and Canada. As the intensity of solar radiation stepped downward in February, the area of greatest cold (see fig. 23) moved southward to the South Atlantic coast, and an area of warmth appeared in northwestern Canada. With a further decreased solar radiation in January, 1919 (see fig. 25), the area of warmth is found in southern Canada and the northern United States, and the area of cold is found in Mexico and the West Indies. With a further decrease in solar energy in January, 1923, the area of greatest warmth (see fig. 27) has moved southward to the southern central United States and the area of cold to latitude about 10° N. to 20° N., near northern South America, while a new area of cold appears in Canada and the northeastern United States.

The areas of excessive rainfall are found within the areas of defective pressure, with the area of greatest warmth to the south or east, and the area of greatest cold to the north or west. Areas of deficient rainfall are found within the areas of excess pressure, with the areas of warmth to the north or west, and cold on the south or east. But rainfall is much influenced by topography and that has to be studied in connection with winds and the distribution of pressure and temperature.

In July the observations extend over a much longer interval than in January, the observations running back to the year 1905, and it was possible to collect data from a large part of the world from the published reports of the various weather services, and from the *Reseau Mondial*. Recent data are missing from Siberia, and observations are scarce over the great oceans, but it is possible by means of the reports from scattered islands like Hawaii, Bermuda, the Azores, the Madeiras, Guam, Fanning, Christmas, St. Helena, South Georgia, South Orkneys, etc., to outline the distribution of pressure over a large part of the oceans. The following months were selected for study, arranged in the order of decreasing intensity of solar radiation :

TABLE 10

Month	Mean solar radiation	Deviations from normal in per cent
July 1917	1.989	+2.3
July 1905	1.972	+1.4
July 1913	1.928	—0.9
July 1910	1.911	—1.8

FIG. 20.

FIG. 21.

Departures from normal Pressure with Solar Radiation one percent above normal. January 1920.

Departures from normal Temperature with Solar Radiation one percent above normal. January 1920.

Departures from normal Pressure with Solar Radiation half percent above normal. February 1920.

Departures from normal Temperature with Solar Radiation half percent above normal. February 1920.

FIG. 22.

FIG. 23.

FIGS. 20-23.

32

Fig. 24.

Fig. 25.

Departures from normal Pressure with Solar Radiation normal.
January 1919.

Departures from normal Temperature with Solar Radiation normal.
January 1919.

Departures from normal Pressure with Solar Radiation one percent below normal
January 1923.

Departures from normal Temperature with Solar Radiation one percent below normal.
January 1923.

Fig. 26.

Fig. 27.

Figs. 24-27.

In round numbers, and probably within the errors of observation, these may be taken as 2 per cent above in July, 1917, 1 per cent above in July, 1905, 1 per cent below in July, 1913, and 2 per cent below in July, 1910.

In figure 28 are outlined the areas of excess and defect of pressure in July, 1917, when the solar radiation averaged 2 per cent above normal. The areas where there was an excess of pressure are shaded, while the areas of deficient pressure are unshaded and the lines of equal departure are broken.

Solar radiation two percent above normal -- July 1917.
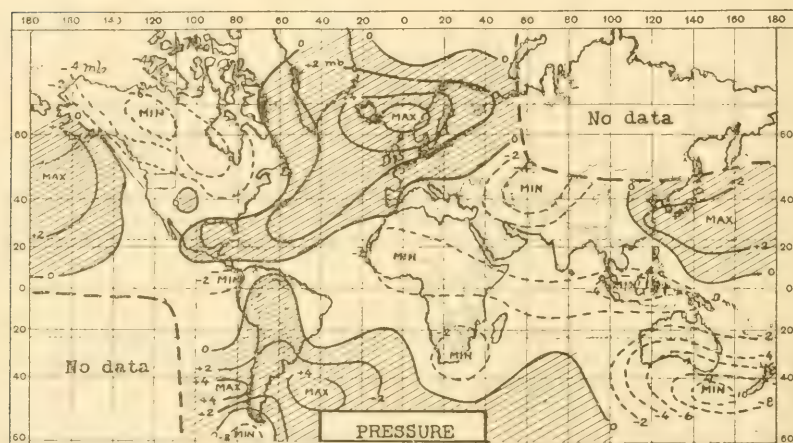
FIG. 28.

It is seen that over the great oceans outside the tropics the pressure is in excess of the normal, while over the continents it is below normal, except in South America. The greatest excess and deficiency are marked by the words " Max." and " Min." respectively. Over the North Atlantic and over North America these centers are in the far north, averaging about 64° N. Over the remaining continents and oceans the data are insufficient to determine the exact position of the " Max." and " Min." except to the extent that they are considerably to the north of the normal position of the high and low pressure centers characteristic of those regions. In the equatorial belt and especially between about 5° N. and 20° S., the pressure is generally below normal.

Figure 29 shows the distribution of pressure in July, 1905, with the mean solar radiation 1 per cent above normal. The areas of excess pressure are again over the great oceans, and there is a defect of pressure over the northern continents and over the tropical parts of Africa and South America. The greatest departures are now found, in general, between the 40th and 50th parallel. In North America and the North Atlantic, this position is some 20° of latitude south of that in 1917. In the equatorial belt the pressure averages below normal, although there is some protrusion of the excess areas of high latitudes into the belt.

Solar radiation one percent above normal -- July 1905.

FIG. 29.

Figure 30 shows the departures from normal pressure in July, 1913, with the solar radiation 1 per cent below normal. Areas of defective pressure now appear over the Pacific and North Atlantic, while there is a belt of excess pressure covering most of the equatorial zone between 40° N. and 30° S. The maximum departures are, in general, between 20° and 30° North and South, that is, about 20° of latitude south of their position in 1905, while a second series of maxima appear over northern Europe and Asia. The belt of low pressure around the poles in the southern hemisphere is nearer the equator than normal, and it is probable that there was an excess of pressure over the Antarctic.

Figure 31 shows the departures from normal pressure in July, 1910, when the solar radiation was 2 per cent below normal. The

defect of pressure over the oceans, both north and south of the equator, is now well defined and a belt of excess pressure extends along the equator except across the Atlantic, Africa, and a part of the Indian Ocean. In this region the defect is very slight and it is possible that a larger number of observations would show that it occupied a much smaller area than shown. The areas of maxima are now very near the equator, being between 0° and 10° latitude south of the equator, and between 15° and 30° north of the equator. In the north there is an excess of pressure north of the 60th parallel,

Solar radiation one percent below normal --July 1913.
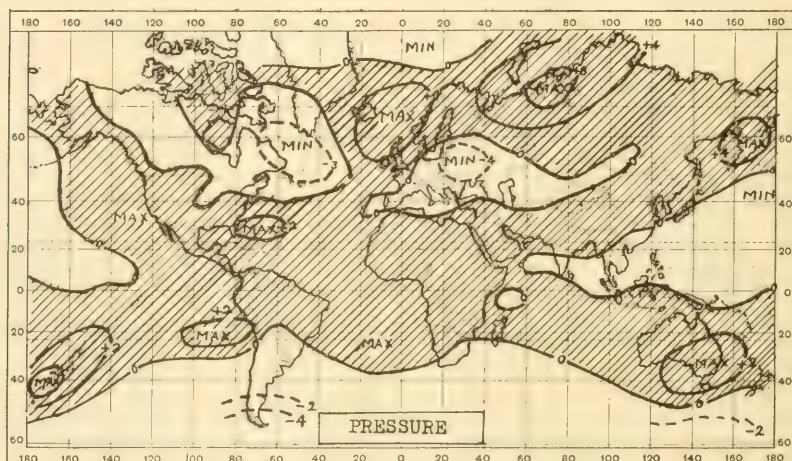
FIG. 30.

probably due to a southward extension of the polar anticyclone, or area of high pressure normally found near the pole.

The succession of maps brings out clearly a steady progress of the excess of pressure over the northern oceans from about 60° N. with solar radiation 2 per cent above normal to about 20° N. with solar radiation 2 per cent below normal.

The area of greatest defect in North America moves from northern Canada in about latitude 64° N., southeastward to the Middle Atlantic in about latitude 45° N. The deficiency in Asia appears to move westward to Europe. In the southern hemisphere the excess of pressure in about latitude 50° S. appears to move equatorward with decreasing solar radiation, followed by a deficiency of pressure which advances from a high latitude with high solar radiation to the latitude of about 30° S. with very low solar radiation.

It is thus made evident that within the tropics the pressure falls with increased solar radiation and increases with decreased radiation, while in high latitudes the centers of high and low pressure swing north and south both in winter and in summer in unison with the variations of solar radiation, but there is a seasonal change in the positions of the centers of high and low over the continents and oceans. This latter fact is brought out clearly by comparing the distribution of excess and deficiency of pressure with high solar radiation in July, 1917 (shown in fig. 28), with the distribution found with

Solar radiation two percent below normal -- July 1910.
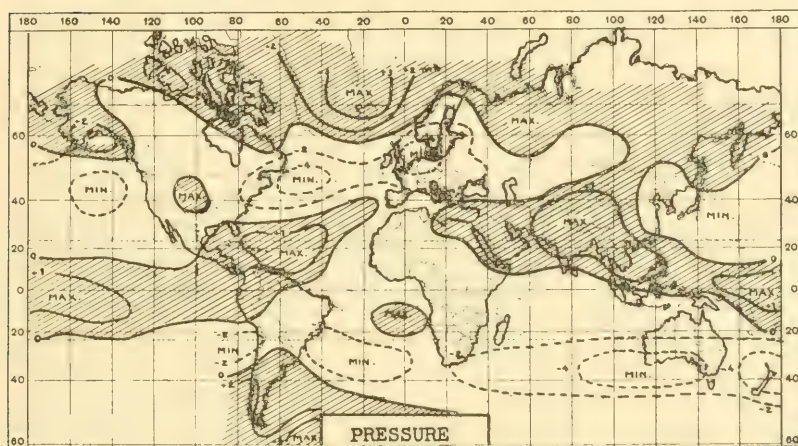
Fig. 31.

high solar radiation in January, 1920 (shown in fig. 20). In both cases there is a defect of pressure in equatorial regions while in high latitudes there is an excess of pressure over the continents in winter with a defect in summer, and the reverse sequence over the oceans.

The polar anticyclone, or area of high pressure, appears also to expand and contract with variations in solar energy, being smallest when the radiation is high, but more observations are needed within the polar circle to make this certain.[1]

If, owing to the difficulties in measuring solar radiation, the given variations from the mean are too large, so that 2 per cent, let us say, should be 1 per cent, then the results are even more impressive of the power of solar changes to produce changes in our atmosphere.

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[1] For further evidence see World Weather, pp. 264-265.

SUNSPOT PERIOD – PRESSURE
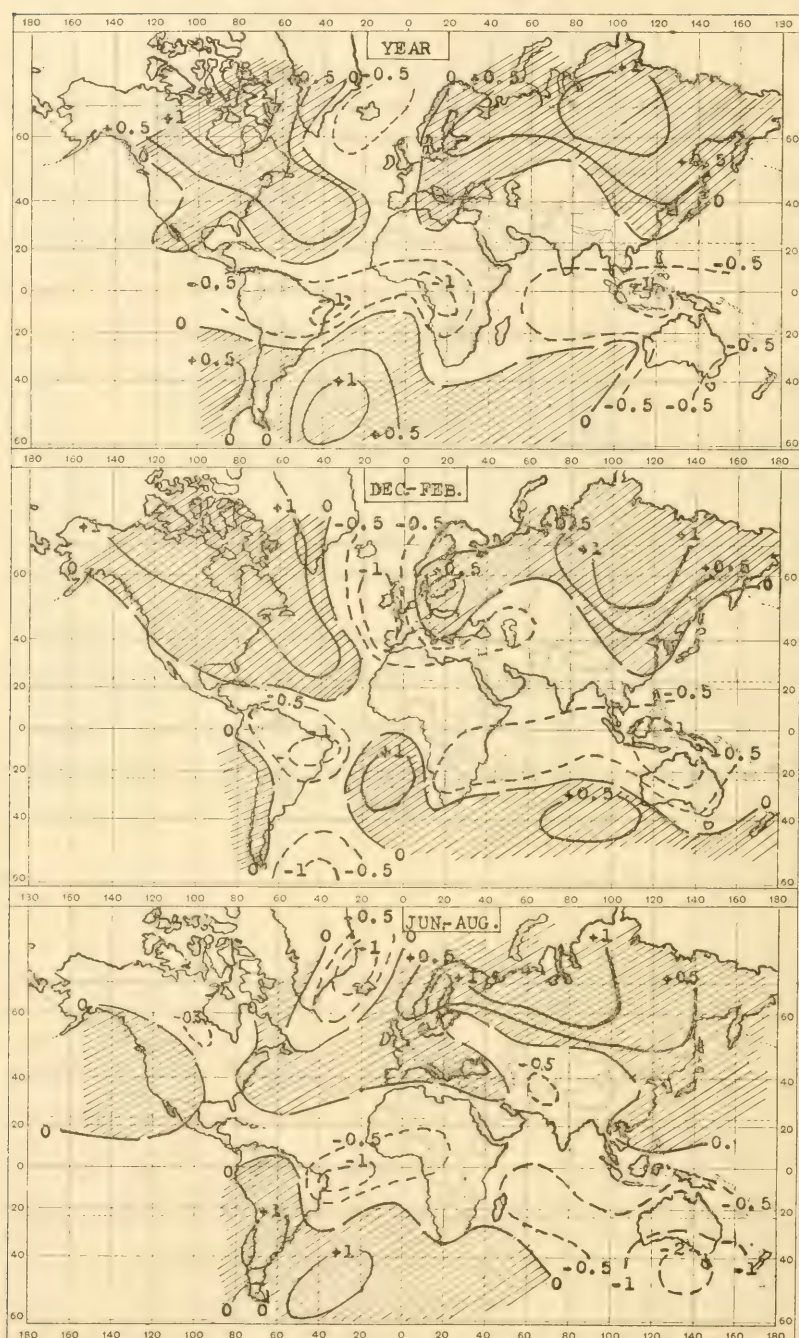
FIG. 32.—Shaded areas show where the pressure is higher at sun-spot maximum than at sun-spot minimum. Broken lines show where the pressure is lower at sun-spot maximum than at sun-spot minimum. The numbers at ends of lines indicate millibars.

That the pressure in the equatorial regions is lower at all times of the year with the increased solar radiation which Dr. Abbot [2] has found at the time of maximum sun spots is evident from an examination of figure 32. The upper chart in this figure shows the mean annual excess and defect of pressure for the years around sun-spot maximum as contrasted with the mean pressure of the years around sun-spot minimum. The middle chart shows the differences·found in the same way for the three months of winter, while the lower charts show the difference for the three months of summer. In each case the pressure is lower at maximum sun spots in the equatorial regions

SUNSPOT PERIOD - RAINFALL.
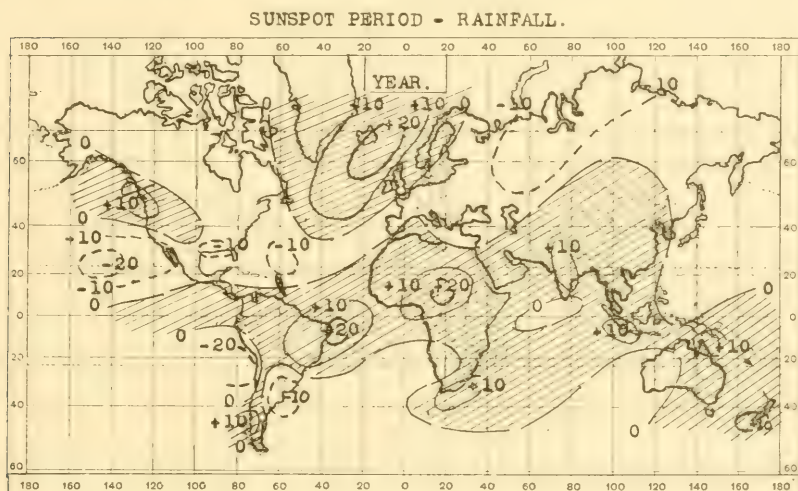
FIG. 33.—Shaded areas show an excess of rainfall at the time of sun-spot maximum. Broken lines indicate a deficiency of rainfall at the time of sun-spot maximum. Figures at end of line give percentages of excess or deficiency of rainfall over that at minimum spots.

and higher in middle latitudes. The fact that the belts of excess pressures in middle latitudes are nearer the poles than the normal positions of the middle latitude high pressures, proves that these belts are displaced toward· the poles with the increased radiation at the time of maximum sun spots in the same manner as is the case in the short period changes of solar radiation.

There is also shown the same tendency in middle latitudes for the excess of pressure to change with the season from continent to ocean, being high over the continents in winter and over the oceans in summer. The excess of rainfall within the pressure belts of the tropics and over the northern oceans at the time of sun-spot maximum is disclosed in figure 33.

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[2] Smithsonian Misc. Coll., Vol. 77, No. 3, p. 38; World Weather, p. 260.

The similarity of the relations disclosed by examining the various classes of solar heat variation, from those occupying a few days to those occupying many years is striking. That such relations also held through the long cycles of climatic changes disclosed by geology and human history is probable, although concrete evidence is still lacking. The great similarity of the meteorological events which accompanied the glacial and interglacial epochs, to the changes which take place during high and low solar heat variations of comparatively short period, are convincing evidence that solar heat changes played
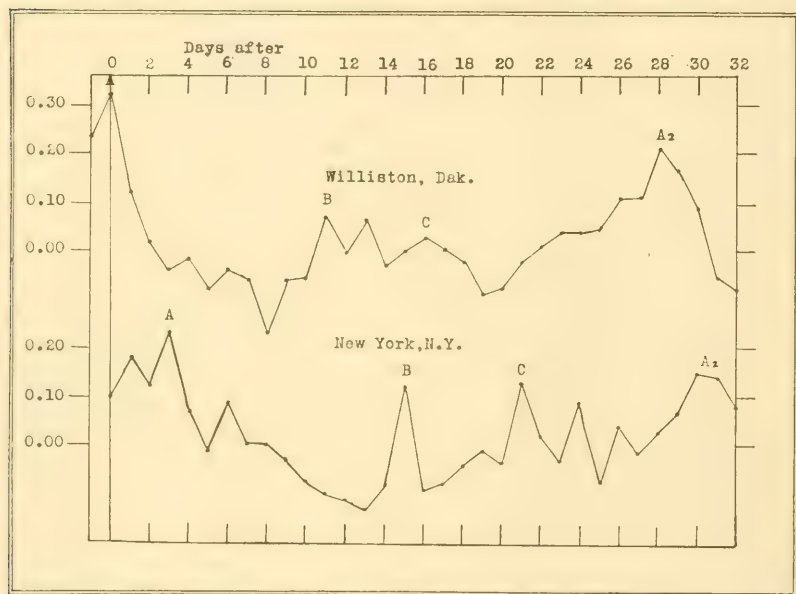
FIG. 34.—Correlation between solar radiation and daily maximum temperature.

an important part in causing those great changes which brought such tragic results to the animal and plant life of the world. The marked fall of temperature in winter which occurs in high latitudes with an increase of only 1 or 2 per cent in solar heat output, shows that a permanent change of that amount or more would produce a serious change in terrestrial climates, and might pile up permanent ice fields like those of Greenland, in middle latitudes where moisture is abundant, and produce an arid cold in continental interiors where moisture is deficient.

It is evident from the foregoing investigations that, owing to the large north and south movements of the belts of pressure and tem-

perature in high latitudes of the earth in response to changes in solar radiation, there could not be a high direct correlation between the day-to-day weather changes at any one station and the day-to-day changes in solar radiation. But in order to determine approximately how large such a correlation may be for stations in the United States during an interval of a few months when the mean level of the solar output is low and nearly stationary, the departures from normal temperature at Williston, N. Dak., and New York, N. Y., were correlated with solar radiation for the interval January to April, 1924.

TABLE 11.—*Correlation between Solar Radiation and Maximum Temperatures of Williston, Dak., and New York, N. Y., for Same Day and 32 Days Following Observations of Solar Radiation, January-April, 1924.*

Day	0	1	2	3	4	5	6	7	8	9	10
Williston	.32	.12	.01	—.04	—.02	—.08	—.04	—.06	—.17	—.06	—.06
New York	.10	.18	.12	.23	.07	—.01	.09	.00	.00	—.03	—.07

Day	11	12	13	14	15	16	17	18	19	20	21
Williston	.06	.00	.06	—.03	.00	.03	.00	—.02	—.09	—.08	—.02
New York	—.10	—.11	.13	—.08	.12	—.09	—.08	—.04	—.01	—.03	.13

Day	22	23	24	25	26	27	28	29	30	31	32
Williston	.01	.04	.04	.04	.11	.11	.21	.17	.09	—.05	—.08
New York	.02	—.03	.09	—.07	.04	—.01	.03	.07	.15	.14	.08

NOTE: The correlation coefficient for the day preceding the solar observation was for Williston 0.24.

The mean correlations for 32 days following the observed values of solar radiation and for one day preceding at Williston are given in table 11. These are plotted in figure 34, which shows that during this interval there was a distinct maximum correlation at Williston on zero day, that is, on the same day that the solar radiation was measured. Secondary maxima occur 11, 16, and 28 days later, the latter no doubt being due to a return of the same influence by a rotation of the sun on its axis. These correlations are not high, the maximum being only 0.32 on zero day. At New York the maxima of the correlations all come three to four days later than at Williston, but are not so large, the maximum being 0.23 on the third day following the observation of solar radiation.

RELATION OF SOLAR RADIATION AND WEATHER TO THE POSITION OF SUN SPOTS

Another line of research was to determine the relations between solar variations and the spots and faculæ on the sun. A preliminary investigation had disclosed an apparent relation between the positions of spots and the intensity of the heat radiation of the sun (*Nature,* Vol. 107, 1921). In order to determine this relation as fully as possible, all the available data were assembled. These consisted of observations published by the Greenwich Observatory from July, 1918, to December, 1921, of visual observations made at La Plata and Pilar, Argentina, from January, 1921, to April, 1924, furnished me by William Hoxmark, and of observations made in Canton,

TABLE 12.—*Mean Solar Radiation in Relation to Position of Sun Spots.*

	Days before							Spot in cen- ter	Days after							
	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7
Large spots	39	40	42	41	37	42	40	36	36	42	41	42	42	41	40
All spots.........	40	38	40	39	38	40	39	37	37	41	38	41	40	40	40

	Days after														
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Large spots	40	40	39	42	38	40	40	40	41	41	40	40	39	40	42
All spots.........	40	40	39	42	38	40	40	40	41	41	40	40	39	40	42

NOTE: The values in the table are to be added to 1.900 so that the first value, for example, becomes 1.939. The number of cases of large spots on zero day was 114 and of all spots, 310.

Massachusetts, from May to July, 1924. The day on which a spot crossed the central meridian of the sun, as seen from the earth, was called zero day, and the observed solar radiation values were tabulated for each of the seven days preceding that date and also for each of the twenty-two days following, thus covering a period of thirty days. The large and small spots were tabulated separately, sums and means were obtained, and then the sums of the two series were combined for obtaining mean results for all spots which crossed the center of the sun from July, 1918, to July, 1924, that is, during an interval of six years.

The Greenwich observations being arranged differently, means were determined separately for the years 1918 to 1921, and 1922 to 1924, and a mean of the two sets of means was obtained. These means of the observed solar radiation values are given in table 12.

These means are plotted in figure 35. The side of the sun on which the spot is located extends from about 6.5 days before to 6.5 days after the central passage of the spot, and the side of the sun opposite the spot extends from about 7 days to 20.5 days after the central passage of the spot.
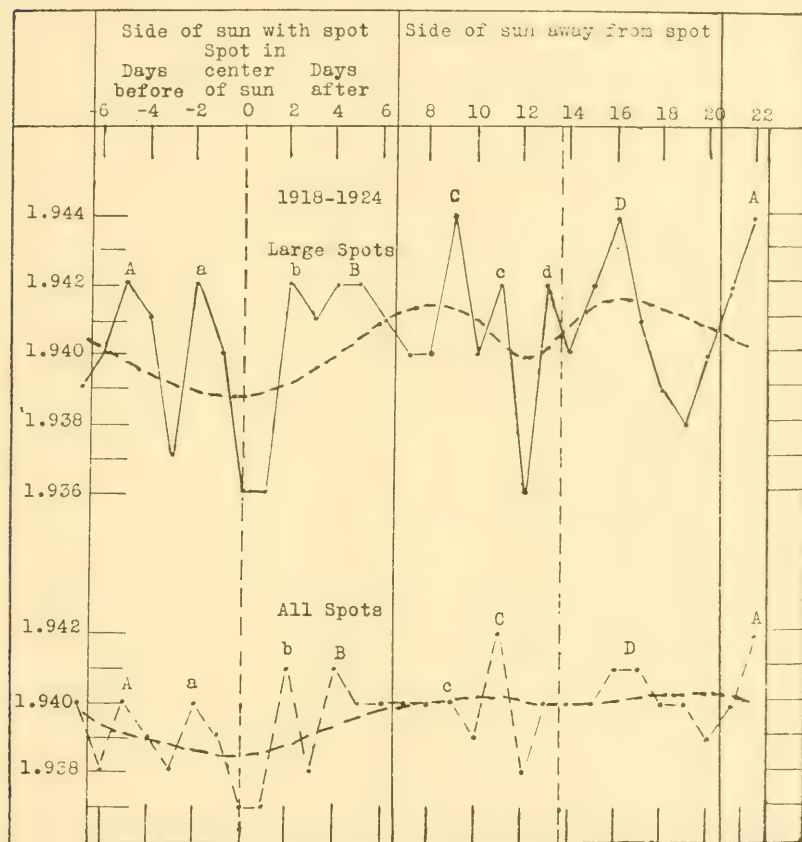
FIG. 35.—Solar radiation in relation to the position of spots on the sun.

A continuous line connects the observed values, and a heavy broken line shows the general sweep of the curve with the small oscillations smoothed out. It is seen that the side of the sun with spots averages colder than the opposite side. There is a tendency, however, to a lower value of the solar radiation on the part of the sun exactly opposite the spot, thus tending to divide the solar rotation into two periods. Examining the shorter oscillations, a marked depression

in the solar radiation is found when the spot crosses the meridian of the sun, and maxima when the spot is near the east and west limb of the sun, at the points marked *A* and *B* in the diagram. In addition there are six other maxima, making eight in all during the interval of the solar rotation, thus giving a mean period of 3.4 days. Taking the maxima *a, B, C, D* in the curve of the large spots, there is found

TABLE 13.—*Mean Solar Radiation in Relation to Sun Spots, 1921-24.*

	Days before							Spot in center	Days after						
	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7
Large spots.......	29	36	37	33	31	35	36	32	30	33	32	36	37	34	35
Small spots.......	28	27	28	27	29	28	27	27	30	27	25	30	29	28	31
Groups...........	29	31	33	29	30	34	32	31	30	31	30	33	34	30	33
Single spots.......	28	30	32	30	29	28	30	27	29	29	27	30	30	32	33
Increasing........	30	35	35	29	32	31	30	33	29	28	27	36	34	32	36
Decreasing	30	29	34	32	26	33	35	28	29	30	32	34	31	30	34
Spots north	23	30	32	31	26	32	27	24	28	28	29	32	34	31	33
Spots south.......	31	30	32	31	31	29	29	28	34	30	25	33	34	34	35

	Days after														
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Large spots.......	33	38	36	39	31	36	33	35	37	34	32	29	33	37	39
Small spots.......	28	28	29	34	31	27	32	29	29	34	31	34	30	28	31
Groups...........	32	33	34	38	33	33	34	34	33	36	33	32	33	35	37
Single spots.......	27	31	28	35	28	28	31	28	31	32	28	31	29	28	30
Increasing........	31	33	32	38	30	29	32	32	32	33	33	32	31	28	36
Decreasing	32	29	34	38	33	31	33	36	36	40	33	33	32	36	37
Spots north.......	32	31	32	31	31	28	31	30	31	32	29	30	32	32	37
Spots south.......	29	31	34	35	28	27	35	29	33	36	36	26	30	34	33

NOTE: The values in the table are to be added to 1.900 so that the first value for example becomes 1.929. The number of cases of large spots is 37 and of small spots 47. The number of groups was 48 and of single spots 36. The number of cases of increasing spots was 34 and of decreasing spots 26. The number of cases of spots 10° or more north of the equator was 31 and 10° or more south of the equator 19.

an exact interval of 7 days and, if these be combined with *A'*, which is a repetition of *A,* there is found a mean interval of 6.8 days. At least from the days of Prof. Joseph Henry down to the present this interval has been noted from time to time in weather changes, and has excited curiosity and comment. That it is related to solar changes is probable, but the reason for these solar changes is not yet evident.

The observations of solar radiation from 1921 to 1924 were selected for more detailed study, first because the solar radiation data were more complete and accurate during this period, and second because the spots were less frequent and there was less confusion from the overlapping of the effects of succeeding groups of spots. The data were tabulated in the manner previously explained after separation into several different classes; first into large spots and small spots, then into groups of spots and single spots, then into spots increasing in size and decreasing in size, and finally into spots north of the equator and south of the equator. The mean radiation for these different classes is shown in table 13.

Figures 36 and 37 show plots of these means. The mean radiation following large spots and small spots, plotted in figure 36, shows the same general trend in each case, the cooler side of the sun being on the side with the spots, but the lesser maxima, A, B, etc., are not distinctly marked in the case of the smaller spots.

In the lower part of figure 36 is plotted the mean solar radiation attending groups of spots and single spots. Here the two sets of mean values are very similar and show that any difference in the solar effect is due to difference in size and not to differences in grouping. Figure 37 shows a plot of the division into classes of spots increasing and decreasing in size, and of spots 10° or more north of the equator and 10° or more south of the equator. The number of cases was not great enough to form very trustworthy means, but in the case of spots increasing and decreasing in size, the only difference appears to be that with increasing spots the general trend of the mean radiation is downward and with decreasing spots is upward, as shown by the differences at the beginning and end of the period. In the case of spots north and south of the equator the details of the plots are different, probably because of insufficient observations, but the general trend shown by the broken curve is the same in both cases.

Next the temperature and pressure at selected stations in the United States were averaged in relation to the position of sun spots.

In table 14 the mean pressure and temperature attending the passage of large spots across the sun is given for Winnipeg and New York, for the interval from 7 days before to 22 days after the passage of the spots across the central meridian as seen from the earth, using all large spots observed from January, 1921, to July, 1924. The number of cases is 41. The results are plotted in figure 38. The first half of the diagram, on the left, shows the changes in the mean
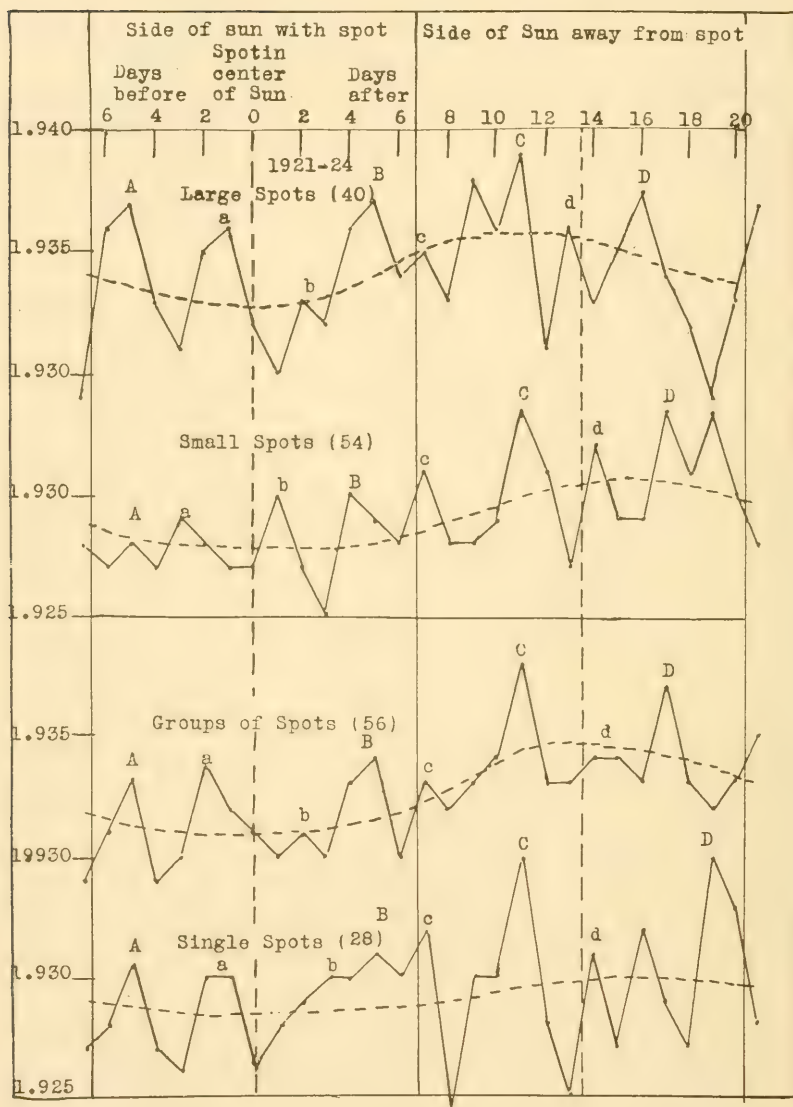
FIG. 36.—Solar radiation in relation to the position of spots on the sun.
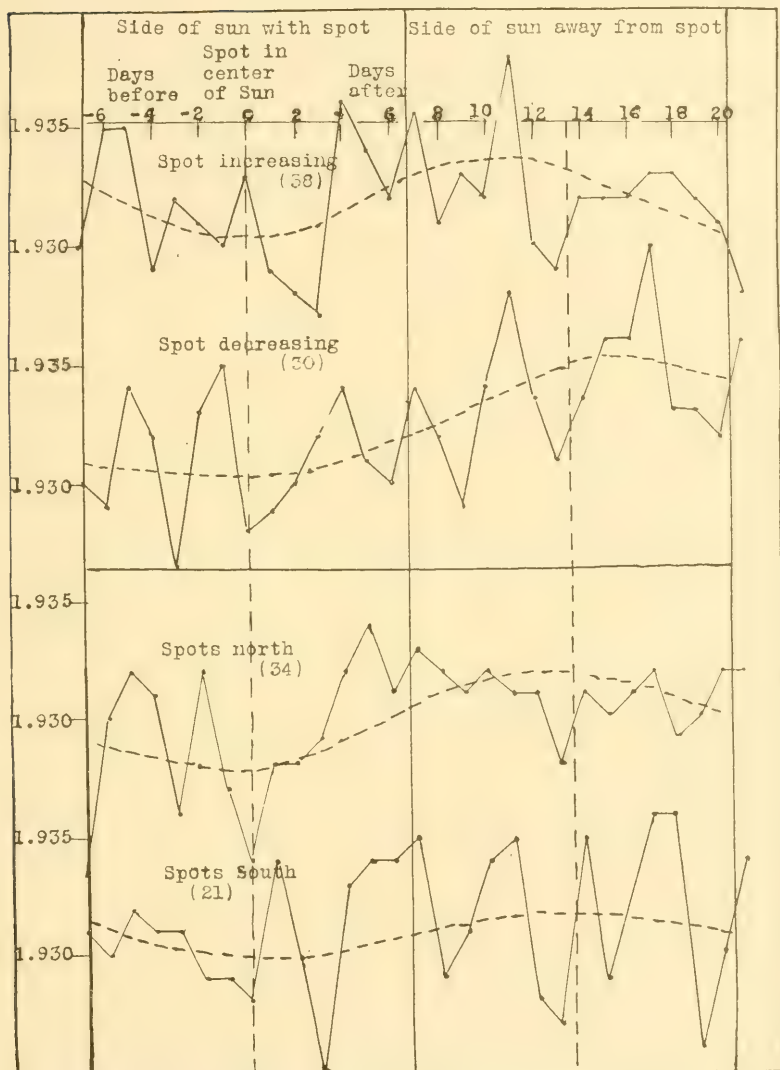
FIG. 37.—Solar radiation in relation to the position of spots on the sun.

solar radiation, in the pressure at Winnipeg, and in the temperature at Winnipeg, when the spot was crossing the side of the sun facing the earth, and the other half of the diagram shows the changes in solar radiation, pressure, and temperature when the spot was on the side of the sun turned away from the earth. The temperature plot is inverted, that is, high temperatures are downward.

It is evident, as said previously, that less radiant energy reaches the earth from the side of the sun on which the spot is located, so that this becomes the cold side of the sun, and the opposite side the

TABLE 14.—*Mean Atmospheric Pressure and Temperature in Relation to Large Sun Spots, 1921-24.*

Days	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Pressure															
Winnipeg...	1.05	1.05	1.00	.98	.91	1.01	1.01	.98	.96	.87	.91	.99	1.01	.95	.97
New York..	1.11	1.11	1.09	1.11	1.14	1.07	1.08	1.06	1.05	1.06	1.08	1.04	1.08	1.13	1.09
Temperature															
Winnipeg...	3.7	3.5	5.2	5.8	6.6	4.1	4.7	4.9	6.1	7.0	6.2	4.5	3.6	6.2	7.0
New York..	2.4	0.4	0.5	1.5	1.0	2.6	2.9	2.3	1.1	0.0	0.3	—0.1	0.0	1.4	2.8

Days	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Pressure															
Winnipeg...	.97	.99	1.03	1.03	1.06	1.09	1.12	1.06	1.04	1.00	1.02	1.04	1.01	1.02	1.06
New York..	1.04	1.00	1.04	1.06	1.06	1.01	.99	.97	1.03	1.07	1.06	1.08	1.05	1.04	1.07
Temperature															
Winnipeg...	6.4	4.8	5.7	5.4	5.0	3.4	3.4	5.4	6.4	6.6	4.1	4.4	6.3	4.7	5.3
New York..	1.4	—0.3	—0.2	0.0	1.9	1.4	0.9	—0.1	0.7	1.3	1.7	2.2	1.5	1.3	1.2

NOTE: Add 29.00 to values of pressure. Temperature is departures of daily maximum from normal in degrees Fahrenheit.

warm side. The amount of radiant energy reaches its lowest level about the time the spot crosses the central meridian of the sun.

The shorter fluctuations as well as the general trend of the curves are strikingly alike in the solar radiation and in the pressure and temperature of Winnipeg during the time the spot is visible, but the relation is not so evident for the opposite side of the sun, probably because the observations on which the means depend are very broken and farther from the date of observation. The maximum "A" of solar radiation occurs soon after the spots and faculæ appear on the eastern limb of the sun, and the maximum " B " occurs shortly before the spots and faculæ reach the western limb of the sun. As
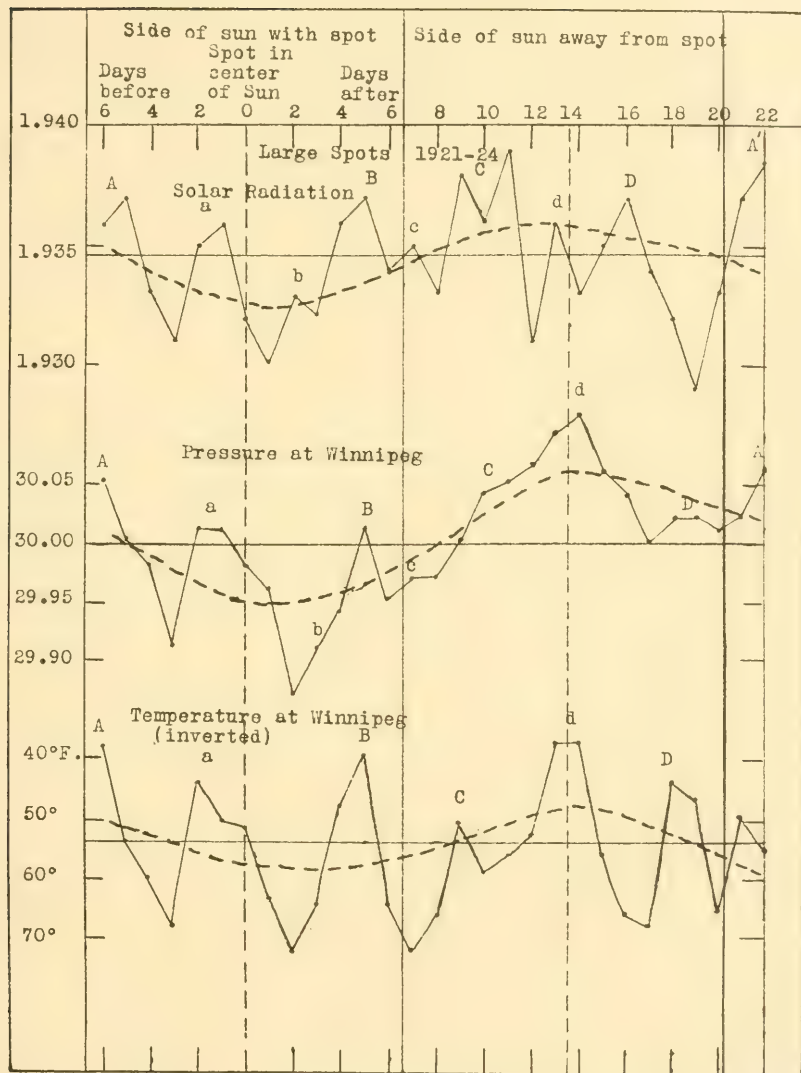
Fig. 38.—Solar radiation in relation to the position of spots on the sun, compared with pressure and temperature at Winnipeg for same days.

shown later, there is an increased solar radiation when the faculæ are in that position. Simultaneously, or nearly simultaneously with the occurrences of these maxima of solar radiation, there are maxima of pressure and minima of temperature at Winnipeg, while with the minimum of solar radiation, when the spot is near the central meridian of the sun, there is a minimum of pressure and a maximum of temperature at Winnipeg. From this central continental region in which Winnipeg is located the pressure waves progress southward and eastward, reaching stations like New York about three to four days later.

The reasons for the maxima C and D are not so evident, but as mentioned before, they are probably related to periodic or semi-periodic changes within the solar mass, especially as they are found in almost every class of solar changes.

Departures from normal temperature were next obtained and studied by seasons for several stations in the United States and Canada. Dividing the year into four parts, the first three months, January to March, were called Winter, the next three months, April to June, were called Spring, the three months, July to September, Summer, and the three months, October to December, Autumn.

The mean temperature departures by seasons for the dates preceding and following the central passage of sun spots are given in table 15 for Winnipeg, Chicago, New York, and Father Point. When thus subdivided, the number of large sun spots was not sufficient to form satisfactory means, so that all observed sun spots were used. The number of cases were: Winter, 20; Spring, 30; Summer, 25; Autumn, 25. The results for the four divisions of the year at Winnipeg from seven days before to ten days after the central passage of the spots is plotted on the left hand side of figure 39. The results for the four seasons show a striking resemblance, and thus furnish proof of the existence of short-period changes in the sun dependent on the position of sun spots. Apparently, however, the effect comes somewhat later in summer than in winter. This delay is more evident when the mean of several stations is taken. Allowing one day for the drift of atmospheric changes from Winnipeg to Chicago, and another day to Father Point, the mean results for the three stations were obtained from the data in table 15, and are plotted on the right-hand side of figure 39 for the interval from five days before to eleven days after the central passage of the sun spots. A distinct seasonal lag is here indicated. The maxima and minima occur about one day earlier in winter than in spring and autumn,

TABLE 15.—*Mean Air Temperature in Relation to the Position of Sun Spots, 1921-24, by Seasons.—Departures from Normal Daily Maximum Temperature.*

WINNIPEG

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	6.8	6.8	7.2	9.4	7.0	3.5	1.0	5.2	7.4	9.4	5.8	7.5	7.3	8.1	7.7
Spring...	1.0	0.2	1.7	2.9	3.0	1.0	0.6	1.0	4.0	2.9	3.0	1.9	2.8	5.0	6.5
Summer..	1.6	0.8	0.7	2.2	2.4	3.0	3.7	0.1	2.8	2.9	4.3	4.2	1.6	2.1	2.3
Autumn..	8.5	9.8	8.1	6.6	9.7	8.6	9.0	5.1	5.1	8.1	10.8	4.4	3.5	9.0	11.4

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	7.2	1.2	5.3	3.2	5.2	3.3	—1.0	2.8	6.3	4.6	3.2	0.9	3.4	4.6	8.4
Spring...	3.2	2.2	1.6	3.4	0.7	1.7	2.7	0.8	3.2	3.2	1.4	3.2	5.4	2.5	4.2
Summer..	4.0	3.2	3.3	3.3	5.4	1.6	3.4	3.9	1.6	2.1	2.1	2.5	2.6	3.6	3.8
Autumn..	8.5	7.1	8.5	8.8	7.5	7.6	7.0	10.3	8.6	11.6	8.0	9.9	11.0	9.7	7.9

CHICAGO

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	2.4	—.06	2.4	0.4	5.7	3.2	2.3	—0.9	0.2	3.2	—0.3	1.9	0.6	8.2	5.9
Spring...	0.4	—1.8	—0.2	0.1	1.7	3.0	2.7	0.8	0.5	2.1	5.5	0.7	2.9	2.1	6.9
Summer..	—0.6	—0.2	0.8	—0.1	0.3	—0.8	0.4	1.7	0.2	—2.8	—1.3	0.0	2.5	2.4	—0.1
Autumn..	1.8	0.8	1.3	—0.1	0.3	0.9	2.9	2.7	—1.1	1.4	2.4	0.7	2.0	—1.2	2.8

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	4.6	5.9	5.4	1.0	0.5	—0.2	—1.2	0.6	—1.0	—0.7	—2.2	—0.8	—2.3	—0.8	—2.6
Spring...	5.6	4.5	3.3	0.5	0.2	2.2	1.6	1.1	2.5	2.8	0.6	0.0	—0.3	0.0	—0.8
Summer..	1.0	1.2	—0.1	2.4	0.7	1.4	—1.6	—0.6	2.3	0.7	—0.9	—1.4	0.1	—1.0	—0.6
Autumn..	3.8	2.9	1.8	2.5	0.4	1.2	—1.0	3.4	1.4	2.0	5.4	4.3	2.5	3.0	3.5

NEW YORK

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	6.1	2.9	2.1	2.9	1.9	7.6	6.2	3.0	1.5	—0.1	0.1	—0.1	0.8	0.7	5.6
Spring...	3.8	1.7	0.1	1.0	—0.8	—0.5	3.1	3.0	—0.3	—1.7	1.1	3.4	0.7	0.1	1.8
Summer..	—0.1	—0.6	—1.2	0.5	0.4	—1.8	—0.8	—0.1	—0.2	0.8	0.0	—0.8	—0.7	0.0	0.9
Autumn..	0.8	0.4	0.6	4.0	3.1	—0.3	—0.4	1.8	2.1	—1.0	0.1	0.5	2.1	1.6	—1.5

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	2.2	1.8	1.4	4.0	5.0	3.2	3.2	1.0	2.2	2.8	1.2	2.6	2.2	0.3	—2.4
Spring...	1.8	—0.4	1.1	2.4	2.5	0.0	0.0	1.0	—0.4	0.2	0.6	1.4	—0.7	0.0	0.4
Summer..	1.4	1.5	0.7	1.1	1.5	0.0	—1.6	—1.2	—1.2	0.7	0.2	—1.3	—0.1	0.0	0.2
Autumn..	1.0	1.0	—0.2	—0.5	0.4	0.6	—1.0	—2.2	1.4	—1.0	0.0	3.0	1.6	6.0	0.8

FATHER POINT

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	—2.2	—2.9	—2.8	—0.2	—1.5	4.1	1.7	1.0	—0.6	—1.6	0.2	—0.3	—1.4	—3.0	0.4
Spring...	1.3	—0.5	—1.0	—1.8	—0.9	0.1	0.1	—0.3	—0.9	—1.1	0.0	—2.0	1.8	0.1	—1.3
Summer..	0.9	—0.5	0.2	—0.2	—0.8	0.5	—0.8	1.2	—1.9	—0.9	—2.9	—1.4	1.9	3.6	0.9
Autumn..	—1.3	—0.8	0.6	0.0	—1.9	—1.7	—1.8	—1.2	—1.7	—0.8	—2.8	—1.4	—1.1	—2.6	—4.2

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	—0.7	—0.9	—3.9	—1.1	1.6	0.4	—0.5	—2.9	—3.7	0.5	2.2	1.9	—0.5	—0.4	—2.3
Spring...	—0.6	—1.7	—0.2	0.5	0.3	1.3	0.9	1.3	2.7	2.3	1.0	0.0	—0.2	0.4	.00
Summer..	—0.5	1.3	0.5	1.8	0.1	—2.7	—2.9	—2.1	—1.8	—0.7	—2.5	—0.4	0.0	0.1	—2.4
Autumn..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

and about two days earlier than in summer. Allowing for this lag there is a correlation for the interval plotted of 0.63±0.10 between winter and spring, a correlation of 0.61±0.11 between spring and summer, and a correlation of 0.43±0.14 between summer and autumn. These correlations are clear proof of the influence of short-period
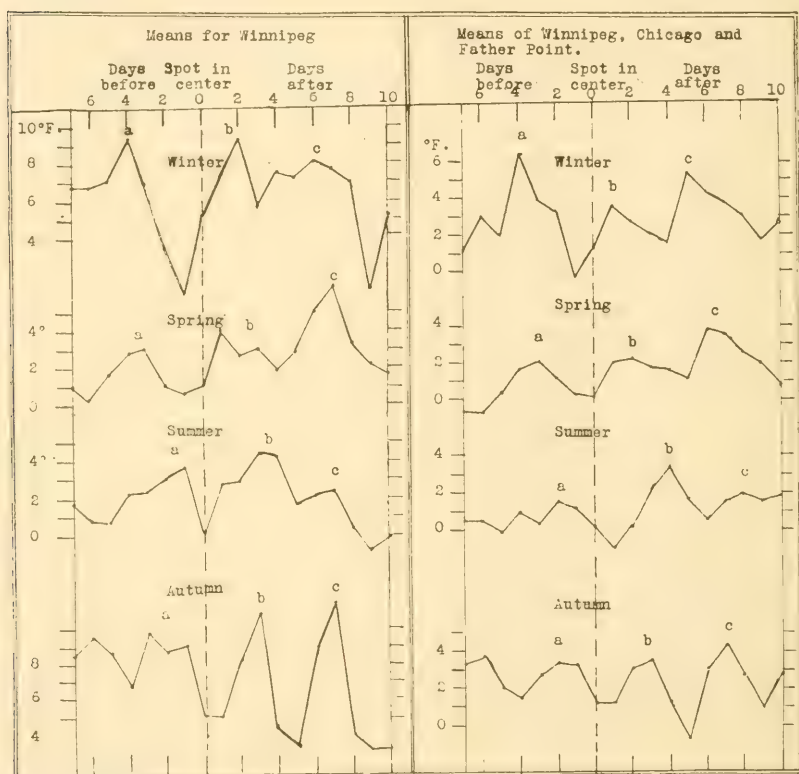
Fig. 39.—Mean departures from normal maximum temperature in relation to the position of sun spots.

solar changes on the earth's weather, entirely independent of measurements of solar heat radiation and indirectly are a strong confirmation of the existence of such changes as shown by the measurements of Dr. Abbot and his colleagues.

RELATION OF SOLAR RADIATION TO FACULÆ

Faculæ are seen as a rule only on the east and west limb of the sun, and are invisible in the center of the sun.

The Greenwich Observatory publishes a table giving the amount of faculæ visible on the sun each day. From these tables the dates of each successive maximum of faculæ were taken from July, 1918, to December, 1921, and tabulated with solar radiation on the day on which the maximum of faculæ occurred, and for two days before and two days after. The number of cases was over 200. The mean solar radiation for each day is given in table 16.

TABLE 16.—*Mean Solar Radiation with Maxima of Faculæ, 1918-1921.*

	Days before		Max. of faculæ	Days after	
	−2	−1	0	1	2
Mean Year	1.9477	1.9466	1.9493	1.9475	1.9480
Mean Apr.-Sept.	1.9455	1.9453	1.9505	1.9469	1.9458
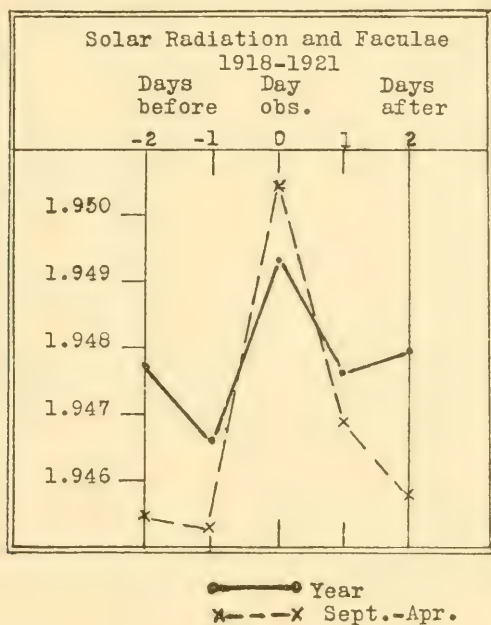
FIG. 40.

The means are plotted in figure 40. The continuous curve shows the means for the whole period, while the broken curve shows the means for the period April-September, when observing conditions are best. The curves show a marked maximum of solar radiation on the day of the maximum of faculæ. The increased radiation shown by the observations of April to September amounts to about one-third of 1 per cent.

In figure 41 are plotted the mean values of solar radiation asso-
ciated with faculæ separately observed on the east and west limbs
of the sun, derived from observations at the Observatory of La Plata
in the years 1920 and 1921. The continuous line shows the mean
solar radiation for the interval from one day before to 14 days after
the appearance of faculæ on the east limb of the sun, and the broken
curve shows the mean solar radiation for 12 days before and two days
after the appearance of faculæ on the west limb. The plot shows
that there was a sharp maximum of faculæ at zero day when the
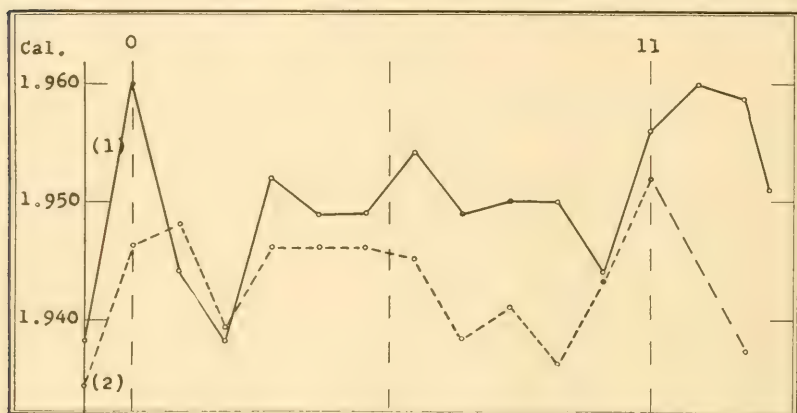
Fig. 41.—Mean values of solar radiation associated with faculæ on sun's limb.
(1) Mean solar radiation one day before and fourteen days after appearance of
faculæ on east limb of sun. (2) Mean solar radiation 12 days before and 2
days after appearance of faculæ on west limb of sun.

faculæ were first seen on the east limb, and also a maximum 11
to 13 days later. There was also a sharp maximum when faculæ
were first seen on the west limb of the sun (11-day on plot) and
another maximum 10 to 11 days earlier.

FORECASTING FROM SOLAR RADIATION DATA

The severest test of knowledge is prediction. Our researches give
clear proof of a connection between solar variations and weather
changes, but at the same time show that the relation is a complex
one. The question arose: Is it possible to base weather forecasts on
this knowledge, and to what degree of accuracy? Weather forecasts
based on observations of solar phenomena were already being tried in

Argentina, and Dr. Abbot was anxious to know whether such forecasts could be successfully made for other parts of the world. After considering the matter, it was decided to try forecasts of temperature for some particular point in the United States, and New York City was selected because of its great importance as a commercial center, and because its weather changes were known to be highly complex, so that if weather forecasts could be successfully made for that point they could probably be made for any part of the northern hemisphere.

It was agreed that the annual change of temperature should be eliminated by determining the normal maximum temperature for each day in the year, and that forecasts of departures from the normal maximum temperature of each day should be attempted. It was further agreed that the forecasts should be verified by averaging the temperature in three different classes. The days for which high temperature was predicted were to be classed together, and the average departure of the observed temperature from the normal was to be determined for that day and for two days preceding and following. The days for which normal temperature was predicted were to be treated in the same way, and also the days for which low temperature was predicted. It was understood that in order to be successful the temperature should average above normal when high temperature was predicted and below normal when low temperature was predicted. It was further decided that the forecasts should be stated numerically, and that forecasts of 5° or more above normal should be forecasts of high temperature, forecasts of +4° to −4° should be considered normal, and forecasts of 5° or more below normal should be considered forecasts of low temperature.

Forecasts were to be made for three, four, and five days ahead, and also for 27 days ahead. After a preliminary test of shorter intervals ahead for two months, forecasts were begun, in accordance with the plan outlined, about December 1, 1923. Also tests were made as to the possibility of forecasting the mean temperature of the coming week and month, making the forecasts three days ahead of the beginning of the week or month.

All these forecasts were verified by Dr. Abbot and Mr. Farmer at the Smithsonian Institution, by means of data collected by them from official sources, and were later checked by Mr. Eliot C. French and myself in Canton, Massachusetts.

The mean results of the forecasts for three, four, and five days ahead are given in table 17, zero day being in each case the day for which the forecasts were made.

TABLE 17.—*Verification of Temperature Forecasts Made for New York City for the Year December 1, 1923 to December 1, 1924.—Mean Maximum Temperatures.*

Fore-cast	Above Normal					Normal					Below Normal				
Days	−2	−1	0	1	2	−2	−1	0	1	2	−2	−1	0	1	2
3 days ahead	+1.86	+2.45	+1.62	+1.20	+1.15	−1.87	−1.28	−0.64	−0.37	−0.61	+2.24	−0.33	−0.97	−0.96	−0.29
4 days ahead	+0.26	+0.71	+0.96	+0.22	+0.02	−0.37	−0.14	−0.21	+0.09	+0.07	+0.22	−1.13	−1.28	−1.33	−0.96
5 days ahead	+0.64	+1.29	+0.45	+0.85	+0.27	−0.51	−0.51	−0.07	−0.24	−0.13	+0.47	−0.15	−0.83	−1.29	−1.41

The number of cases three days ahead were: above normal, 103; normal, 189; below normal, 73. Four days ahead they were: above normal, 100; normal, 209; below normal, 54. Five days ahead they were: above normal, 78; normal, 223; below normal, 59.

A summary of the results for the days for which the forecasts were made is as follows:

TABLE 18.—*Summary of Verifications of 3- to 5-day Forecasts.*

Temperature forecast	High	Normal	Low	High-Low
3 days ahead of data..............	+1.6	−0.6	−1.0	+2.6
4 days ahead of data..............	+1.0	−0.2	−1.3	+2.3
5 days ahead of data..............	+0.5	−0.1	−0.8	+1.3 [1]

[1] The difference between the mean temperature following forecasts of high temperature five days in advance and that following forecasts of low temperature for the seven months Dec. 1924 to May 1925 is 2°.1, showing increasing accuracy in the forecasts with increasing knowledge.

The mean results for the weekly and monthly forecasts were as follows:

TABLE 19.—*Verification of Weekly and Monthly Forecasts of Mean Maximum Temperature.*

Temperature forecast	Above normal	Cases	Below normal	Cases
For the week, from 3 days ahead of week's beginning	+0.37	30	−1.85	20
For the month, from 3 days ahead of month's beginning	+0.16	10	−4.20	2

At first the 3- to 5-day forecasts were based largely on the relations shown in figures 2 and 3, later these were supplemented by direct observations of the sun and the relations shown in figures 38 and 39

were also used in forecasting. These were supplemented by tele-
grams of the maximum temperature observed at Seattle, Williston,
and Chicago, in order to ascertain to what extent the temperatures
at those stations were responding to solar changes.
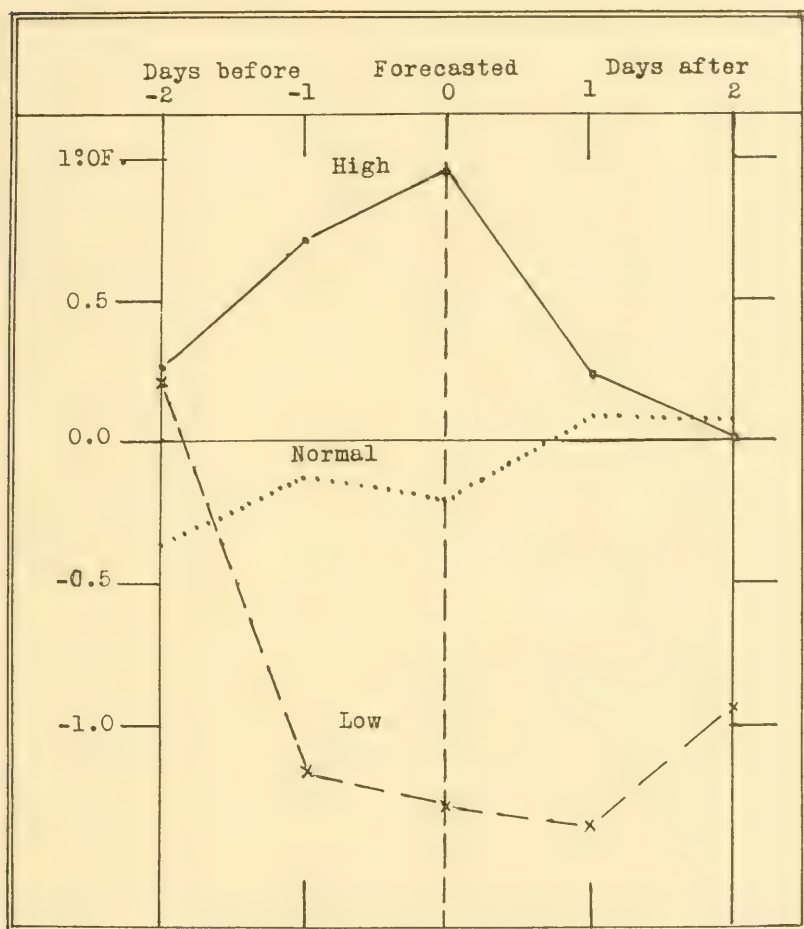
FIG. 42.—Mean temperature at New York forecasted four days in advance.

A plot of the mean temperatures following the forecasts for
four days ahead is given in figure 42. This figure shows that when
temperature above normal was forecasted, the mean temperature
rose from near normal two days following the observations on which
the forecast was based to a maximum departure on the day for which

the forecast was made, and declined to near normal two days later. For normal forecasts the mean temperature was slightly below normal at the beginning of this interval, and slightly above at the end. For forecasts of temperature below normal the temperature was slightly above normal two days after the observations, and fell to a minimum on the fourth to fifth day. There was a rise on the sixth day, but the temperature did not return to normal until later.

This curve demonstrates conclusively that on the average we succeeded in making forecasts of the daily maximum temperature at New York for four days ahead and that we were not aided in doing so by prolonged departures from the mean on one side or the other of the normal. Whether accurate forecasts could be made for such an interval in advance by any other method I am not prepared to say, but heretofore no one has made definite forecasts for such an interval in advance and submitted them to a third party for verification by a method which does not permit personal bias to influence the results.

The averages in table 19 show that for three days in advance successful forecasts were also made of the mean temperature of the following week and month.

The detailed forecasts for 27 days in advance based on the return of similar conditions by a solar rotation were not successful, but this by no means indicates that such forecasts will not be possible when solar conditions and their relations to terrestrial phenomena are better understood.

In carrying out forecasts based on solar data at the present time, serious difficulties beset the forecaster:

(1) The measurements of solar radiation are frequently prevented by cloudiness, so that sometimes for two or three successive days observations may be missing. At other times the accuracy of a measurement is uncertain or doubtful, and at all times there is a certain amount of error.

(2) The effect on the earth's atmosphere of variations in solar heat radiation differs with the season, and with different intensities of solar radiation, so that it is necessary to determine and to keep in mind the effect of both these variables.

(3) Each new solar influence is superimposed on pre-existing conditions. In some cases, if not in all, these conditions arise from progressive movement of weather changes from one center of action to another. In Argentina, for example, it was found that at certain seasons an increase of solar radiation produces a fall of pressure and a rise of temperature in northwestern Argentina and southwestern

Brazil, while simultaneously there is a rise of pressure and a fall of temperature in southern Argentina. Progressive changes coming from the south frequently overlapped those forming in the north.

(4) There are other variables which are probable, but the effect of which has not yet been determined. For example, any distribution of pressure resulting from solar changes, if long continued over ocean areas, must set in motion ocean currents which in turn cause surface changes in temperature and pressure.

It is gratifying to know that notwithstanding these difficulties forecasts have been successfully carried on for a year. A rigid mathematical method of verification proves them to be better than chance forecasts for an important station in the United States. There is every reason to suppose that these forecasts will go on increasing in accuracy as the data on which they are based increases in completeness and accuracy, and the knowledge of how these solar changes affect our atmosphere increases.

PREDICTION OF SOLAR RADIATION CHANGES

Figure 34 brings out clearly that, in order to predict weather changes which follow solar radiation changes so closely as they do at Williston, it is necessary to anticipate the solar changes. In order to test the accuracy with which this could be done from visual observations of sun spots and faculæ, beginning in May, 1924, a forecast was made of the solar radiation to be expected five days ahead of the observed phenomena. At first these were filed, but after July 1, 1924, were mailed as soon as made to Dr. Abbot. Figure 43 gives a plot of the predicted and observed values of solar radiation. A dotted curve joins the forecasted values of solar radiation from May to September, inclusive, on all the days on which observed values were obtained and a continuous curve joins the observed values. All days on which there were no observations or on which there were doubtful observations were omitted.

Besides the absolute values of solar radiation, a forecast was also made each day as to how much the solar radiation would depart from the general trend as determined by 27-day means of consecutive observations.

These forecasts were verified by Mr. Eliot C. French,[1] and checked by Dr. Abbot in the same way as were the temperature forecasts

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[1] I am also indebted to Mr. French for assistance in the preparation of the data presented in this paper and for making forecasts during periods when I was absent, and to Misses H. V. Miller and M. I. Robinson for assistance in the computations.
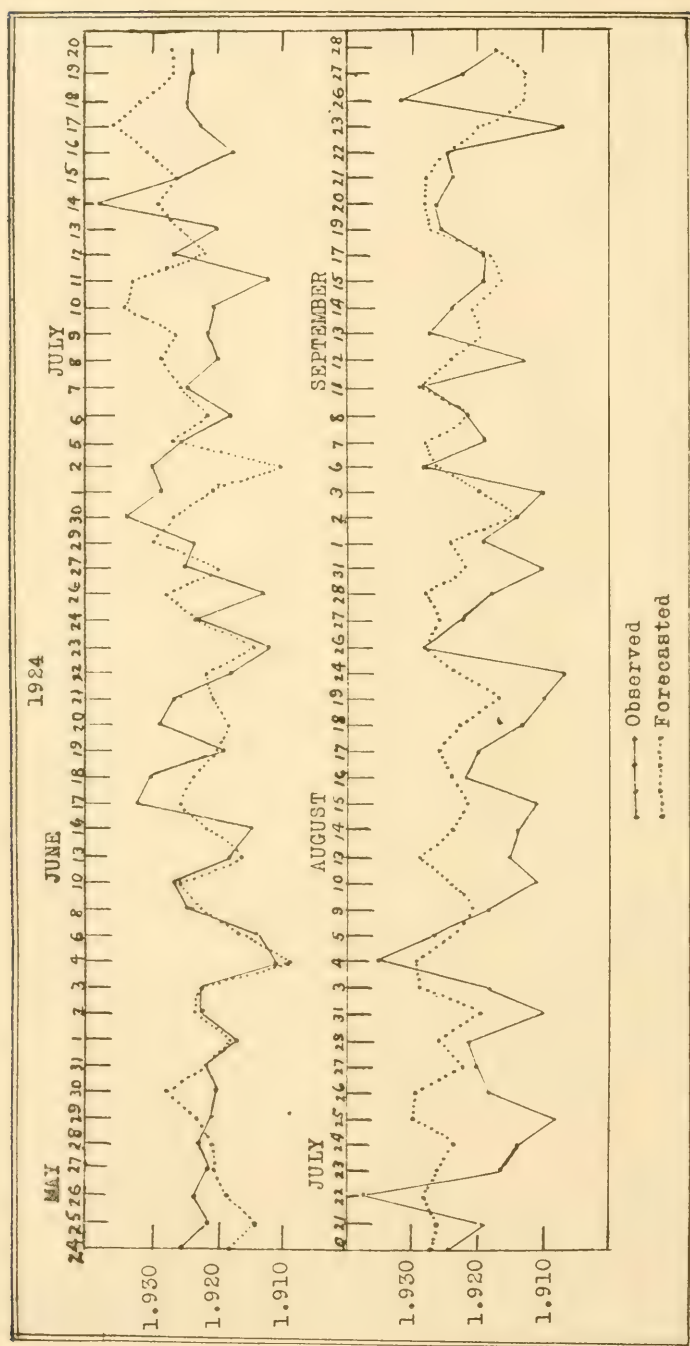
Fig. 43.—Comparison of observed and predicted values of solar radiation five days ahead.

made three to five days in advance. A forecast of +.005 calorie or
more was considered a high value, +.004 to —.004 a normal value,
and —.005 calorie or below was considered a low value.

The mean results for six months (May to October, 1924) are
given in table 20:

TABLE 20.—*Mean Observed Values of Solar Radiation Following
Forecasts Five Days Ahead.*

Forecasts	Cases	Days before −2	−1	Forecasted 0	Days after 1	2
Above normal	39	+.0008	+.0013	+.0024	+.0018	+.0004
Normal	97	+.0003	+.0001	+.0004	—.0006	—.0003
Below Normal	21	—.0008	—.0011	—.0038	—.0015	—.0016
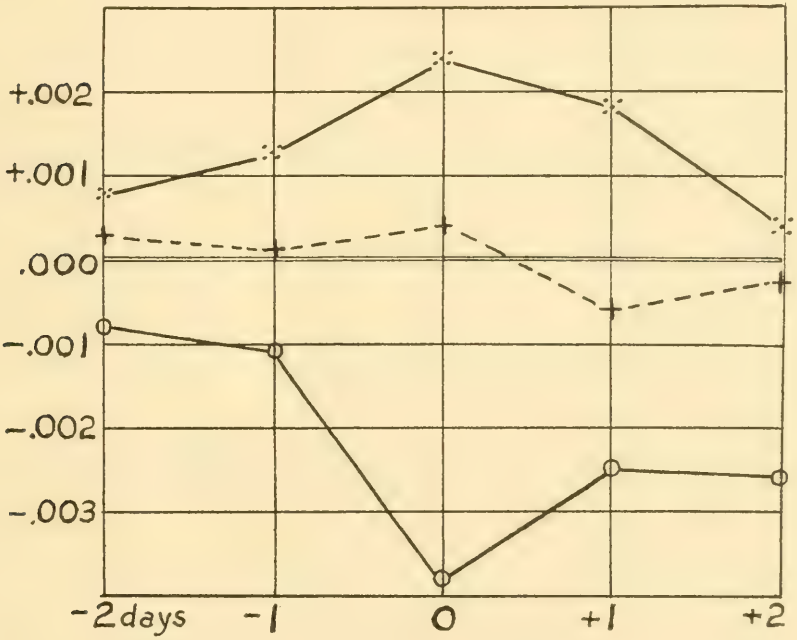
FIG. 44.—Mean observed solar radiation following forecasts 5 days ahead.

These results are plotted in figure 44. They prove conclusively
that the solar radiation can be predicted with some success for five
days ahead from observations of visual phenomena on the sun. The
mean of the observed departures rises to a sharp maximum on the
day for which the forecast was made (zero-day). The mean
observed solar radiation following normal forecasts is seen to average
normal, and that following forecasts of low values is seen to fall to
a sharp minimum on the day for which the forecast was made.

SOLAR RADIATION

Curves showing observed values, and predicted values
made on and for same day.
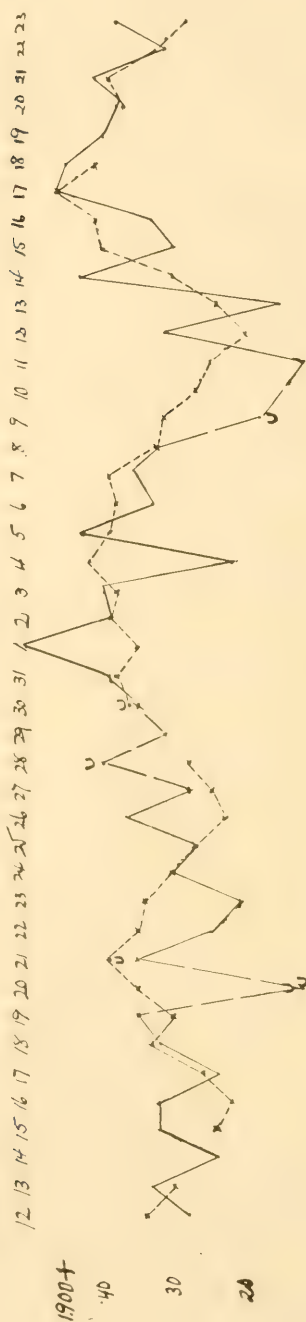
—————— Observed Solar Radiation.

--------- Predicted solar radiation, made on and for same day.

Fig. 45.

In 1925 the forecast was changed to a prediction of the value of solar radiation to be expected on the same day as that on which the faculæ and spots were observed. These forecasts are forwarded to Washington about 24 hours before the observed values of solar radiation are received at Canton. A plot of the observed values (full line) and the predicted values (broken line) is given in Fig. 45 for March and April, 1925. The letter *u* indicates that the observation was uncertain. It is seen that the general trend of the solar changes was predicted but not the detailed changes. In other words the solar radiation was more variable than shown by visible phenomena.

A THEORY OF THE METHOD BY WHICH SOLAR HEAT CHANGES AFFECT ATMOSPHERIC CONDITIONS ON THE EARTH

The rapidity with which the pressure rises in high latitudes of the earth when the solar radiation increases and in turn falls when solar radiation decreases, indicates that the influence is exerted in some way directly on the atmosphere itself and not indirectly through changes at the earth's surface. The atmospheric changes appear to occur at the centers of action simultaneously with the solar changes or at most there is a delay of only a few hours. It seems to me probable that an increase of solar radiation heats the upper air, more particularly in the equatorial belt where the sun is nearly vertical. There results from this heating an expansion of and a movement of the air from the equatorial belt which causes the pressure to fall within that belt and to rise in high latitudes, determined by the lower mean temperature of those latitudes and the influence of a rotating earth on moving air. That such an influence can be exerted rapidly at a great distance is shown by the rise of pressure in high latitudes coincident with the diurnal fall of pressure in tropical and subtropical regions.

This is the primary effect of the increased solar radiation and remains more or less the same throughout the year, because the relation of pole to equator remains the same, modified to some extent by the north and south movement of the sun. It may be called the first variable.

A second variable arises from the distribution of land and water. The land is colder than the water in high latitudes in winter and warmer in summer. This difference determines an increase of pressure with an increase of solar radiation over the continents in winter and a fall over the oceans, and a reversal of this effect in summer. This reversal of the effect with the seasons in high latitudes becomes most marked with slow and prolonged changes in the mean values

of solar radiation. This latter influence probably results from or is aided by absorption and radiation of heat from the earth's surface, as well as by direct absorption and radiation of heat by the atmosphere. The independence of these two variables should be kept clearly in mind. The first remains more or less constant throughout the year, while the second reverses between winter and summer.

A third variable is the atmospheric drift, carrying with it the air circulations around high and low pressure areas. In part, this variation in drift results from variations in the general atmospheric circulation and in part from variable contrasts of air temperature over large areas of the earth's surface.

A fourth variable is perhaps a readjustment of the pressure and temperature due to the movements of ocean currents set up by the winds attending the distribution of pressure determined by the causes enumerated above. The study of Helland-Hansen and Nansen proves that the movement of ocean currents cannot be the primary cause of pressure changes, but they may produce a modifying effect.

The longitudinal shifts, that is, the east to west shifts of the centers of action attending solar heat changes are not yet fully understood, and there may be other variables in the solar action not yet disclosed.

A clearer idea of the theory here outlined may be gained by studying the diagrams in " World Weather," [1] more especially figures 58, 62, 101, 102, 107, and 109.

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[1] "World Weather," by Henry Helm Clayton. Cloth, 393 pages, 265 figures and illustration, 16 plates. For sale by Eliot C. French, Canton, Massachusetts, U. S. A., $4.00 postpaid.

SOLAR RADIATION AND THE WEEKLY WEATHER FORECAST OF THE ARGENTINE METEOROLOGICAL SERVICE

BY

GUILLERMO HOXMARK

INTRODUCTORY NOTE

By C. G. ABBOT,

ASSISTANT SECRETARY, SMITHSONIAN INSTITUTION

In publishing Mr. Hoxmark's paper, the Smithsonian Institution is glad to bring to the notice of English-speaking people the results which have come from the acceptance of the evidence of solar variability as a working hypothesis by the Weather Service of Argentina. The preliminary investigations in this line by Mr. H. H. Clayton, when he was official forecaster of Argentina, were published by the Institution in Volume 68, No. 3, of the Smithsonian Miscellaneous Collections, and these studies led to the attempt to forecast temperatures and precipitation at Buenos Aires based on solar-radiation measurements made by the Smithsonian observers at Calama and Montezuma, Chile.

These forecasts, begun in December, 1918, by Mr. Clayton, and continued since June, 1922, by his successor, Mr. Hoxmark, have given rise to the present paper by the latter. The temperature forecasts are given not in general terms such as most forecasters content themselves with using, but state precisely for a narrow locality the exact temperatures to be expected, morning and evening, to the end of the eighth day after the forecast is published. Verification consists in taking differences between observed and forecasted temperatures and the normal depending on many years records, and computing correlation coefficients therefrom, according to the well known methods of Galton and Pearson.

This, it goes without saying, is a very severe test. An error of 12 hours in the time when a sharp rise or fall of temperature is predicted, even though the reality and magnitude of the change is truly forecasted, will often give large departures which ruin for the time the correlation between forecast and event. Moreover, the results of Clayton, which appear in the next preceding serially numbered paper of these Miscellaneous Collections, show that even a half per cent change in solar radiation produces notable temperature changes. The accuracy of Smithsonian solar-radiation observations is not adequate to prevent many errors as great as half of one per cent, or even twice that magnitude occasionally. Hence, on this account, also, the solar forecaster is at a disadvantage.

TABLE A.—*Hoxmark's weekly correlation coefficients segregated by months*

Numbers of cases and mean values between certain limits of time and percentage magnitudes of positive and negative correlations

Months		0–15 Plus	0–15 Minus	15–30 Plus	15–30 Minus	30–45 Plus	30–45 Minus	45–60 Plus	45–60 Minus	60–75 Plus	60–75 Minus	75–100 Plus	75–100 Minus	Total Plus	Total Minus	Total both signs
Jan.	No. / Mean	0 / —	2 / 11	1 / 15	1 / 28	1 / 37	1 / 36	2 / 53	0	0	0 / —	0 / —	0 / —	4 / 40	4 / 28	8 / +
Feb.	No. / Mean	1 / 3	0	2 / 17	1 / 20	1 / 43	0 / —	0	2 / 46	1 / 63	0 / —	0 / —	0 / —	5 / 28	3 / 37	6 / +
Mar.	No. / Mean	2 / 8	0 / —	1 / 23	0	0 / —	2 / 41	0	0 / —	2 / 65	1 / 70	2 / 93	0 / —	7 / 51	2 / 42	8 / +
Apr.	No. / Mean	0	0	0 / —	1 / 21	0	1 / 34	0 / —	0	4 / 67	2 / 69	2 / 85	0 / —	6 / 56	3 / 42	4 / +
May	No. / Mean	1 / 7	1 / 7	2 / 24	0	0	0	1 / 57	0 / —	0	0 / —	0 / —	0 / —	4 / 25	4 / 60	9 / +30
June	No. / Mean	2 / 9	0	1 / 19	1 / 23	2 / 35	0	5 / 52	2 / 51	1 / 75	1 / 70	1 / 89	1 / 95	8 / 40	1 / 23	9 / +24
July	No. / Mean	2 / 9	0 / —	3 / 24	0 / —	1 / 38	0	0 / —	2 / 51	1 / 60	3 / 67	1 / 82	1 / 82	8 / 32	6 / 56	8 / +
Aug.	No. / Mean	1 / 0	1 / 6	2 / 29	0	3 / 39	1 / 40	0 / —	1 / 52	3 / 69	0	1 / 96	0	10 / 48	3 / 33	17
Sept.	No. / Mean	2 / 8	0	3 / 23	3 / 23	2 / 36	1 / 41	0 / —	0	1 / 61	0 / —	1 / 97	0 / —	9 / 40	4 / 27	9 / +33
Oct.	No. / Mean	2 / 7	1 / 9	0 / —	1 / 17	0	2 / 35	2 / 51	0 / —	1 / 72	1 / 70	3 / 87	0 / —	8 / 56	5 / 34	14 / +5
Nov.	No. / Mean	1 / 0	0	1 / 21	2 / 23	1 / 42	0	4 / 49	0 / —	3 / 67	1 / 67	0 / —	0 / —	10 / 46	3 / 38	13 / +29
Dec.	No. / Mean	0	0 / —	3 / 19	4 / 18	3 / 37	0	0 / —	2 / 48	1 / 67	0	1 / 75	0 / —	8 / 39	6 / 28	13 / +19
Year	No. / Mean	13 / +5	5 / 9	19 / +22	14 / 21	14 / +38	8 / 38	11 / +51	7 / 49	18 / +67	8 / 69	12 / +88	2 / 88	87 / 44	44 / 39	131 / +16
Dec. Jan. Feb.	No. / Mean	1 / 3	2 / 11	6 / 18	6 / 20	5 / 38	1 / 36	2 / 53	4 / 47	2 / 65	0	1 / 75	0	17 / 36	13 / 17	30 / +13
May Oct.	No. / Mean	3 / 7	2 / 8	2 / 24	1 / 17	0 / —	2 / 35	3 / 53	0 / —	1 / 72	3 / 71	3 / 87	1 / 95	12 / 46	9 / 46	21 / +
Mar. Apr. June July Aug. Sept. Nov.	No. / Mean	9 / 5	1 / 6	11 / 24	7 / 23	9 / 38	5 / 39	6 / 49	3 / 51	15 / 67	5 / 67	8 / 90	1 / 82	58 / 44	22 / 40	80 / +21

Furthermore, Mr. Clayton's early studies proved that the sign of correlation between solar changes and the temperature changes at Buenos Aires alternates between plus and minus from summer to winter. There are transition months, May and October, when it is sometimes indeterminate. Besides this, the months December, January, and February have always proved the most unfavorable of the year for the Smithsonian solar radiation work, not only in Chile but in Arizona, on account of disturbed sky conditions.

It occurred to me, therefore, to analyse Mr. Hoxmark's 131 weekly correlation coefficients with reference to the time of the year. Also, I noted in a cursory inspection that there were few small correlation coefficients, but nearly all were large, either positive or negative. Hence, I rated them according to magnitudes, and kept separated the weeks in which his forecasts correlated with the right sign from the

TABLE B.—*Summary of Table A*

Percentages	Separate signs Number of cases						Both signs Number of cases		
	0–30%		30%–60%		60%–100%		0–30%	30%–100%	Total
	+	—	+	—	+	—			
Month-group									
Dec., Jan., Feb....	7	8	7	5	3	0	15	15	30
May, Oct.	5	3	3	2	4	4	8	13	21
Remaining months.	20	8	15	8	23	6	28	52	80
Totals	32	19	25	15	30	10	51	80	131

weeks in which he erred as to sign. The result seems to me very illuminating, and is given in table A. Some of the outstanding features of table A are gathered in table B.

From this analysis there stand out clearly:

1. The months December, January and February are the poorest, as was to be expected, because the radiation data are then poorest.

2. The months May and October, although yielding a large percentage of high correlations, are unsatisfactory because so many of these large correlations are negative to the event.

3. All remaining months of the year yield much better results.

4. It is remarkable that over 60 per cent of the weeks forecasted yield correlation coefficients exceeding 30 per cent.

5. It is unfortunate that of the large correlation coefficients nearly one third are of the wrong sign. This, of course, brings down the average positive correlation to the low figures of 16 per cent for all months and 21 per cent for the best 7 months, as shown in table A.

6. One is impressed by these very large negative correlations, that they are not accidental, but are real correlations and full of meaning but reversed because some governing factor is neglected. If they had all been of the correct sign, and without altering the signs of coefficients less than 30 per cent, which may well be of a more accidental character, the average correlation coefficients for the entire 131 weeks would have risen to over 37 per cent.

7. Readers of the next preceding serially numbered paper of these Miscellaneous Collections, by Mr. Clayton, will have noted that he has discovered an enormous shift in latitude of cyclones and anticyclones depending on absolute values of the solar constant. May it not be that Mr. Hoxmark, by further investigation along those lines, will find such additional relations for Argentina as will enable him to obtain correct signs of correlation in the numerous cases of incorrect but high correlations, so that his future forecasts can be notably improved? It would seem that a special study of the conditions surrounding the cases of high correlations of incorrect sign, which he is here reporting, might lead him to new points of view, which would prove very helpful in future.

ACKNOWLEDGMENTS

SOLAR RADIATION AND THE WEEKLY WEATHER FORECAST OF THE ARGENTINE METEOROLOGICAL SERVICE

By GUILLERMO HOXMARK

The Argentine Meteorological Service publishes every Wednesday a weekly weather forecast, the forecast zone being the federal capital (Buenos Aires) and the region of the River Plata.

The prediction is issued in the form of a curve diagram wherein exact values are given of temperature to be expected at 8 a. m. and 8 p. m., for each day of the coming week. The rain forecast is given in an accompanying note.

This forecast was initiated during the Directorship of Mr. G. Wiggin by Mr. H. H. Clayton, with the author as collaborator.

The basis for the predictions, which began with December 12, 1918, was the measurements of solar radiation expressed in calories per square centimeter per minute, transmitted by cable from the Solar Observatory in Calama, Chile, maintained by the Smithsonian Institution of Washington, D. C. The solar-radiation data have also been used for more extensive investigations covering the whole earth. Results of these researches have been presented in several papers.[1]

Owing to unfavorable conditions, the solar-radiation measurements were often discontinued during days and sometimes weeks, so that it became necessary to find some other method of calculating solar changes.

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[1] Effect of Short Period Variations of Solar Radiation on the Earth's Atmosphere, by H. H. Clayton. Smithsonian Misc. Coll., Vol. 68, No. 3, 18 pp., 8 charts, 2 diagrams, Washington, D. C., May, 1917; also in Spanish " Boletin Mensual," Junio, 1916. Oficina Meteorologica Argentina.

Variations in Solar Radiation and the Weather, by H. H. Clayton. Smithsonian Misc. Coll., Vol. 71, No. 3, 53 pp., 5 pls., 17 figs., Washington, D. C. Jan. 15, 1920; and " Boletin Mensual," Febrero, 1918. Oficina Meteorologica Argentina.

La Maxima De La Radiation Solar En Enero Y Febrero De 1920.

Y El Estado Del Tiempo Mundial, H. H. Clayton y Guillermo Hoxmark, " Boletin Mensual," Junio, 1919, 18 pp., 9 figs., 2 cuadros. Oficina Meteorologica Argentina (included in " World Weather " Chap. X).

World Weather, by H. H. Clayton. 393 pp., 265 figs. and illustrations, 16 pls., New York, 1923.
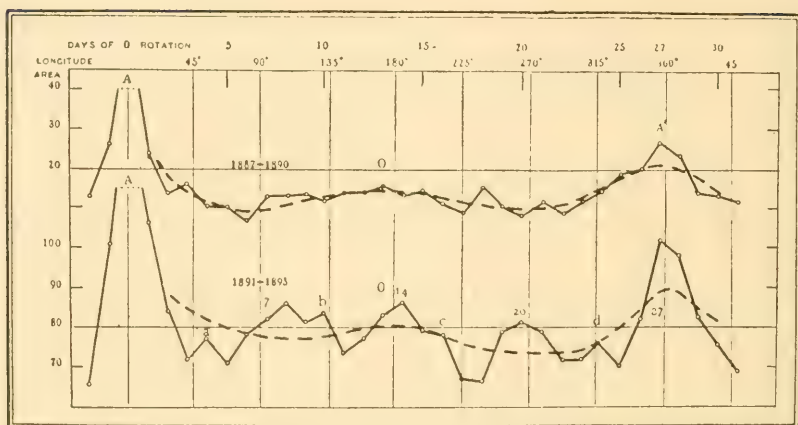
FIG. 1.—Mean distribution of faculæ in longitude on sun following marked outbreaks of faculæ.

FIG. 2.—Relation of solar radiation to area and intensity of faculæ.

As Dr. C. G. Abbot had found that there is a relation between the visible phenomena of the sun and the solar radiation intensities, an arrangement was made with the Astronomical Observatory of the University of La Plata to make observations of the sun from August, 1920. Later on, the same class of observations were made by the Magnetical Observatory of Pilar, Argentina, and the Astronomical Observatory at Rio de Janeiro, Brazil. Figure 1 shows the mean distribution of faculae in longitude on the sun following marked outbreaks of faculae, and figure 2 shows the relation of solar radiation to area and intensity of faculae (after Clayton).

Some months after the departure of Mr. H. H. Clayton, until then chief of the forecast department of the Argentine Meteorological Office, when the author took charge of the weekly prediction, the scope of the investigations was widened by including the daily observations of the magnetic components, and from February, 1924, there were included the atmospheric electricity data, from the Pilar Observatory.

To calculate the weekly forecast of the weather, all the various observations previously mentioned, solar radiation, solar faculae, earth magnetism, atmospheric electricity and the meteorological observations are analysed and subjected to an exhaustive and comparative study.

VERIFICATION—TEMPERATURE

The difficulties offered by a weather prognostication for intervals longer than 24 hours, increase considerably with the length of the selected period.

For example, the prediction for the first day of the weekly forecast can be formulated with great accuracy, but as the number of days augment, the technical processes and the calculations must be multiplied to attain the exactitude of the first day, so that it can be stated that the difficulties increase in geometrical progression.

The verification of a forecast formulated in exact numbers, and for a limited territory, does not suffer from the same weakness as that of a prediction published in words, whose true sense afterwards can be made a subject of dispute. The fixed temperatures given by the weekly forecast are very convenient for a mathematical comparison, absolutely free from personal bias.

The method of finding correlation coefficients worked out by Galton and Pearson is much employed at present, and therefore the following equation was used to determine the relations between predicted and observed values.

$$r = \frac{\Sigma XY}{\sqrt{\Sigma X^2 \cdot \Sigma Y^2}}$$

Where X represents the departures from the mean value of the forecasted temperatures, Y the departures from the mean value of the observed temperatures, and r the correlation coefficient. For verification purposes there were employed only the temperature observations from the Villa Ortuzar Observatory, Chacarita, Buenos Aires, though it probably would have been better to have used a mean of several stations around the River Plata.

TABLE 1.—*The method for calculating the correlation coefficient*

August 14-20, 1924

Date	Temperature mean of day		X	Y	X^2	Y^2	XY		
	Predic.	Observ.					+	−	
14	7.0	5.6	−26	−44	7	19	+ 11		Log. 12 = 1.079181
15	8.5	8.8	−11	−12	1	1	+ 1		33 = 1.518514
16	10.0	10.3	4	3	0	0	+ 0		2.597695
17	10.1	10.2	5	2	0	0	+ 0		1.298847
									Log. 19 = 1.278754
18	11.6	13.4	20	34	4	12	+ 7		9.979907
19	10.0	10.9	4	9	0	1	+ 0		r = 0.955
20	10.0	10.5	4	5	0	0	+ 0		
Sum	67.2	69.7			12	33	+ 19	−0	
Mean	9.6	10.0							

The first step was to obtain the mean of the days for the predicted and observed values and these were then used to calculate the correlation coefficient as shown in table 1.[1]

The correlation coefficients will be found in tables 2, 3, 4, 5 and 6, representing two and a half years' forecasts from June, 1922 to

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[1] Objection may be taken by some to the use of separate means by Mr. Hoxmark for predicted and observed temperatures in computing departures. Yet he merely gives himself thereby the slight advantage that he puts his forecasts on the true scale. The variations from day to day are not affected.

TABLE 2.—*Correlation between Predicted and Observed Temperature Departures in the Weekly Weather Forecast for the Region of the River Plata. Mean of the day*

Period July–December, 1922

Year	Month	Week	Correlation Factor
1922	July	29– 5	.25
		6–12	—.68
		13–19	.60
		20–26	—.61
		27– 2	—.82
	August	3– 9	.30
		10–16	—.06
		17–23	.40
		24–30	.68
	September	31– 6	.61
		7–13	.24
		14–20	.42
		21–27	.48
	October	28– 4	.08
		5–11	—.76
		12–18	.99
		19–25	—.39
		26– 1	.51
	November	2– 8	.48
		9–15	.67
		16–22	—.67
		23–29	.21
	December	30– 6	—.20
		7–13	—.16
		14–20	.17
		21–27	.75
		28– 3	.67

TABLE 3.—*Correlation between Predicted and Observed Temperature Departures in the Weekly Weather Forecast for the Region of the River Plata. Mean of the day*

Period January–June, 1923

Year	Month	Week	Correlation Factor
1923	January	4–10	—.26
		11–17	—.36
		18–24	—.08
		25–31	—.14
	February	1– 7	—.47
		8–14	.15
		15–21	—.46
		22–28	.43
	March	1– 7	.95
		8–14	.05
		15–21	.91
		22–28	.67
	April	29– 4	.63
		5–11	.62
		12–18	—.34
		19–25	—.21
		26– 2	.69
	May	3– 9	.07
		10–16	—.07
		17–23	.20
		24–30	.28
	June	31– 6	.38
		7–13	—.23
		14–20	.33
		21–27	.07

TABLE 4.—*Correlation between Predicted and Observed Temperature Departures in the Weekly Weather Forecast for the Region of the River Plata. Mean of the day*

Period July–December, 1923

Year	Month	Week	Correlation Factor
1923	July	28– 4	.19
		5–11	.38
		12–18	.82
		19–25	.00
		26– 1	—.54
	August	2– 8	.28
		9–15	.39
		16–22	—.52
		23–29	—.40
	September	30– 5	—.23
		6–12	.31
		13–19	.97
		20–26	.15
		27– 3	—.22
	October	4-10	.72
		11–17	.51
		18–24	.07
		25–31	—.09
	November	1– 7	.45
		8–14	.57
		15–21	—.17
		22–28	.00
	December	29– 5	.19
		6–12	.35
		13–19	—.16
		20–26	.34
		27– 2	.43

TABLE 5.—*Correlation between Predicted and Observed Temperature Departures in the Weekly Weather Forecast for the Region of the River Plata. Mean of the day*

		Period January–June, 1924	
Year	Month	Week	Correlation Factor
1924	January	3– 9	.57
		10–16	.37
		17–23	.49
		24–30	.15
	February	31– 6	.63
		7–13	.03
		14–20	—.20
		21–27	.20
	March	28– 5	.12
		6–12	—.44
		13–19	—.39
		20–26	.23
		27– 2	.63
	April	3– 9	—.70
		10–16	.74
		17–23	.81
		24–30	.89
	May	1– 7	—.95
		8–14	—.67
		15–21	.57
		22-28	—.72
	June	29– 4	.75
		5–11	.11
		12–18	.19
		19–25	.52
		26– 2	.89

TABLE 6.—*Correlation between Predicted and Observed Temperature Departures in the Weekly Weather Forecast for the Region of the River Plata. Mean of the day*

Period July–December, 1924			
Year	Month	Week	Correlation Factor
1924	July	3– 9	.00
		10–16	—.49
		17–23	—.73
		24–30	.28
	August	31– 6	.67
		7–13	.71
		14–20	.96
		21–27	.39
		28– 3	.00
	September	4–10	.29
		11–17	—.23
		18–24	.08
		25– 1	—.41
	October	2– 8	.85
		9–15	—.17
		16–22	—.32
		23–29	.77
	November	30– 5	.70
		6–12	.42
		13–19	.45
		20–26	—.29
		27– 3	.63
	December	4–10	—.21
		11–17	—.51
		18–24	.22
		25–31	—.45

December, 1924. It is evident that by calculating the correlation for each week independently, all seasonal influences will be eliminated from the results.
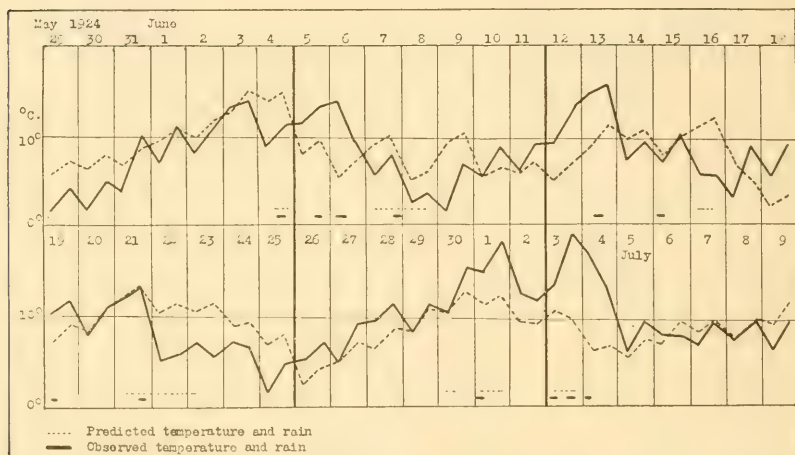
Fig. 3.—The dotted lines show predicted temperature and rain in the Weekly Weather Forecast for six weeks from May 29 to July 9, 1924, and the lines in full show the observed temperature and rain for the same period.
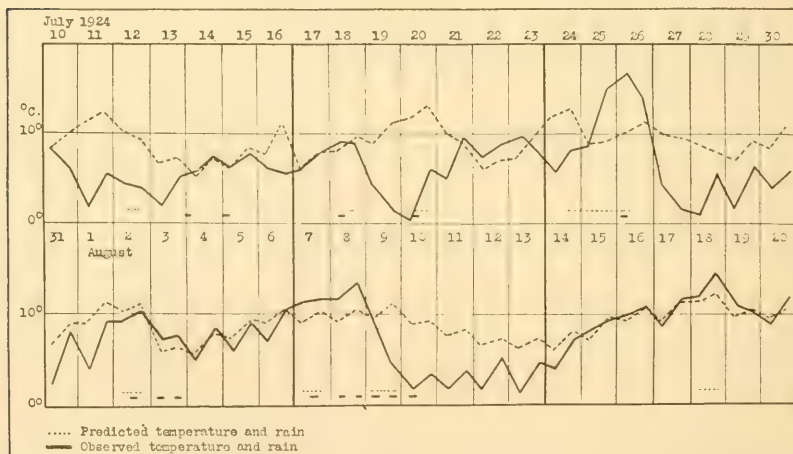
Fig 4.—The dotted lines show predicted temperature and rain in the Weekly Weather Forecast for six weeks from July 10 to August 20, 1924, and the lines in full show the observed temperature and rain for the same period.

Figures 3 and 4 each give six weekly forecasts, from May 29 to August 20, 1924. The dotted lines show predicted temperature and the full lines the observed temperature. Underneath the tem-

perature curves, the predicted rain is indicated by small dots, and the observed precipitation by short heavy lines.

The predicted and observed temperature values at 8 a. m., and 8 p. m., for each day from May 29 to August 20, 1924, will be found in tables 7, 8, 9 and 10, with their corresponding weekly correlation coefficient. The solar-radiation data received by cable from the Montezuma Observatory, Calama, and the solar faculae observations from the Pilar Magnetical Observatory for the same period, are shown respectively in tables 11 and 12.

A negative correlation is not always indicative of absolute failure of a forecast. This is amply illustrated by the two weeks, July 10-16 and July 17-23, 1924.

Glancing at the graph, figure 4, we can see that the observed curve on the eleventh of July shows the maxima indicated by the forecast, though the temperature had fallen several degrees under.

In the second case, on only two days, namely the 19th and the 20th, were the observed values contrary to the forecasted; and yet the correlation coefficients for those weeks turn out to be $-.49$ and $-.73$.

TABLE 7.—*Predicted and Observed Temperature at 8 a. m., and 8 p. m. Predicted Temperature from the Weekly Weather Forecast for the River Plata Region, Observed Temperature from the Chacarita Observatory, Buenos Aires*

Year	Month	Day	Temperature		Correlation Factor
			Predicted	Observed	
1924	May	29	8 a. m. 5.7	1.6	
			8 p. m. 7.2	4.3	
		30	6.7	1.8	
			7.9	5.1	
		31	6.8	3.7	
			8.4	10.2	
	June	1	9.1	7.1	
			10.4	11.2	
		2	9.8	8.2	
			11.5	10.3	
		3	12.5	12.8	
			14.8	14.0	
		4	13.9	8.8	.75
			14.5	11.5	
		5	8.0	11.6	
			9.6	13.3	
		6	5.3	13.9	
			7.3	9.3	
		7	8.9	5.8	
			9.9	8.1	
		8	4.9	2.6	
			6.1	3.5	
		9	9.0	1.7	
			10.2	6.8	
		10	5.4	5.9	
			6.3	8.6	
		11	5.9	6.3	.11
			6.8	9.0	
		12	4.8	9.4	
			6.5	13.0	
		13	8.7	14.5	
			11.2	15.7	
		14	9.7	7.4	
			10.5	9.2	
		15	7.9	7.1	
			9.6	10.1	
		16	10.6	5.7	
			11.9	5.7	
		17	6.9	2.7	
			5.3	9.0	
		18	2.1	5.6	.19
			2.7	9.0	

TABLE 8.—*Predicted and Observed Temperature at 8 a. m., and 8 p. m. Predicted Temperature from the Weekly Weather Forecast for the River Plata Region, Observed Temperature from the Chacarita Observatory, Buenos Aires*

| Year | Month | Day | Temperature | | Correlation Factor |
			Predicted	Observed	
1924	June	19	8 a. m. 7.0	10.4	
			8 p. m. 8.9	12.0	
		20	8.3	7.9	
			11.3	10.8	
		21	11.9	11.9	
			13.1	12.8	
		22	10.3	5.0	
			11.0	5.5	
		23	10.5	6.7	
			11.3	5.7	
		24	8.8	7.2	
			8.9	6.6	
		25	6.7	1.7	.52
			7.7	4.4	
		26	2.2	5.2	
			4.1	7.4	
		27	4.5	4.9	
			7.1	9.1	
		28	6.3	9.3	
			8.3	11.2	
		29	8.0	8.1	
			10.3	11.0	
		30	10.3	10.2	
			12.3	15.1	
	July	1	11.2	14.8	
			11.9	18.4	
		2	9.0	12.2	.89
			8.9	11.8	
		3	10.3	13.6	
			9.5	19.0	
		4	6.1	17.1	
			6.5	13.0	
		5	5.3	6.0	
			7.0	8.9	
		6	6.9	7.6	
			9.1	7.6	
		7	8.0	6.7	
			9.2	8.8	
		8	7.6	7.4	
			9.3	9.4	
		9	8.9	6.2	.00
			11.6	8.8	

TABLE 9.—*Predicted and Observed Temperature at 8 a. m., and 8 p. m. Predicted Temperature from the Weekly Weather Forecast for the River Plata Region, Observed Temperature from the Chacarita Observatory, Buenos Aires*

Year	Month	Day	Temperature		Correlation Factor
			Predicted	Observed	
1924	July	10	8 a. m. 8.2	8.5	
			8 p. m. 9.6	6.5	
		11	11.0	1.9	
			12.2	5.6	
		12	10.4	4.6	
			9.8	4.1	
		13	6.8	2.0	
			7.2	5.3	
		14	5.4	5.8	
			7.0	7.6	
		15	6.4	6.7	
			8.4	7.8	
		16	7.8	6.3	—.49
			11.1	5.8	
		17	6.2	6.1	
			7.9	8.0	
		18	8.1	9.1	
			9.5	9.0	
		19	8.7	3.5	
			11.3	1.2	
		20	11.7	0.4	
			12.9	6.2	
		21	10.0	4.6	
			9.1	9.8	
		22	6.0	7.7	
			6.8	9.3	
		23	6.9	9.9	—.73
			9.8	8.3	
		24	12.0	5.8	
			12.8	8.0	
		25	8.6	8.6	
			9.0	15.3	
		26	10.0	16.8	
			11.2	14.0	
		27	10.0	4.0	
			9.7	1.5	
		28	8.6	1.2	
			8.1	5.9	
		29	7.3	1.5	
			9.2	6.6	
		30	8.6	4.0	.28
			10.6	6.0	

TABLE 10.—*Predicted and Observed Temperature at 8 a. m., and 8 p. m. Predicted Temperature from the Weekly Weather Forecast for the River Plata Region, Observed Temperature from the Chacarita Observatory, Buenos Aires*

Year	Month	Day	Temperature Predicted	Temperature Observed	Correlation Factor
1924	July	31	8 a. m. 6.5	2.0	
			8 p. m. 8.7	7.9	
	August	I	8.9	3.9	
			11.1	9.1	
		2	10.4	9.2	
			10.8	10.2	
		3	5.9	7.3	
			6.0	7.7	
		4	5.5	4.7	
			7.6	8.2	
		5	7.2	6.0	
			9.0	8.7	
		6	8.8	6.9	.67
			10.2	10.3	
		7	9.1	11.3	
			10.4	11.5	
		8	9.3	12.0	
			10.3	13.6	
		9	9.9	9.2	
			11.0	4.1	
		10	8.8	1.6	
			8.9	3.2	
		11	7.7	1.7	
			8.3	4.1	
		12	6.6	1.7	
			7.3	5.4	
		13	6.4	1.3	.71
			7.4	4.6	
		14	5.9	4.0	
			8.2	7.3	
		15	7.5	8.2	
			9.5	9.4	
		16	9.4	9.8	
			10.6	10.8	
		17	9.4	8.6	
			10.9	11.8	
		18	11.1	12.1	
			12.2	14.7	
		19	9.9	11.4	
			10.2	10.4	
		20	9.5	8.8	.96
			10.5	12.3	

TABLE 11.—*Solar-Constant Values, Montezuma Station, Calama, Chile*
June, July, and August, 1924

June	Value	Grade	July	Value	Grade	August	Value	Grade
1	1.935	S	1	1.929	S	1	1.871	U
2	1.933	S	2	1.930	S	2	1.909	U
3	1.933	E—	3	1.926	U	3	1.928	S
4	1.927	S—	4	Clouds		4	1.935	S—
5	Clouds		5	1.917	S—	5	1.927	S—
6	1.934	S—	6	1.916	S	6	1.905	U
7	1.931	U	7	1.918	S	7	Clouds	
8	Clouds		8	1.925	S	8	Clouds	
9	1.929	S	9	1.920	S	9	1.918	S
10	1.941	S—	10	1.922	S	10	1.911	S
11	1.930	U	11	1.921	S	11	1.907	U
12	1.930	S—	12	1.912	S—	12	Clouds	
13	1.919	S	13	1.927	S—	13	1.915	S—
14	Clouds		14	1.920	E—	14	1.914	S
15	Clouds		15	1.937	S	15	1.911	E—
16	1.925	S—	16	1.927	S	16	1.922	S
17	1.931	S—	17	1.918	VG—	17	1.920	S
18	1.931	S—	18	1.923	S	18	1.913	S
19	1.927	S—	19	1.925	S	19	1.910	E—
20	Clouds		20	1.924	S	20	1.844	U
21	Clouds		21	1.919	E—	21	Clouds	
22	1.924	E—	22	1.937	S	22	1.875	U
23	1.921	S	23	1.916	S	23	1.931	U
24	1.934	S—	24	1.914	S	24	1.907	E—
25	Clouds		25	1.908	S—	25	1.908	S
26	1.913	E—	26	1.918	S—	26	1.928	S
27	1.931	U	27	1.920	S	27	1.922	VG+
28	1.925	S	28	1.921	E—	28	1.918	S
29	1.924	VG	29	Clouds		29	Clouds	
30	1.934	S	30	Clouds		30	1.914	U
			31	1.910	S	31	1.910	S—

TABLE 12.—*Pilar, Magnetical Observatory, Lat. 31° 40' 13" S., Long. 63° 53' 00" W. Results of Solar Faculae observations*

June, July, and August, 1924

June	Area	July	Area	August	Area
1	175	1	35	1	140
2	0	2	Cloudy	2	Cloudy
3	0	3	0	3	Cloudy
4	Cloudy	4	Cloudy	4	166
5	Cloudy	5	Cloudy	5	195
6	160	6	70	6	Cloudy
7	Cloudy	7	242	7	86
8	0	8	185	8	Cloudy
9	0	9	70	9	0
10	100	10	95	10	0
11	80	11	Cloudy	11	170
12	0	12	Cloudy	12	Cloudy
13	0	13	Cloudy	13	180
14	0	14	0	14	140
15	50	15	Cloudy	15	133
16	118	16	315	16	175
17	110	17	Cloudy	17	Cloudy
18	Cloudy	18	Cloudy	18	Cloudy
19	Cloudy	19	Cloudy	19	28
20	66	20	Cloudy	20	0
21	Cloudy	21	0	21	0
22	Cloudy	22	60	22	50
23	0	23	90	23	33
24	35	24	0	24	Cloudy
25	Cloudy	25	Cloudy	25	110
26	15	26	160	26	200
27	44	27	Cloudy	27	105
28	75	28	165	28	68
29	131	29	150	29	15
30	172	30	138	30	0
		31	60	31	Cloudy

The area is the combined area of all the daily solar faculae observed, multiplied by their degree of luminosity or intensity, which is expressed as I, II and III.

VERIFICATION—RAINFALL

In the following verification of precipitation predicted in the weekly weather forecast, only rain fallen within the small zone in heavy shading on the accompanying map, figure 5, has been used, and days with fog and great humidity which did not materialize into rain were not included.

Atmospheric changes over the region of the River Plata usually cover a great area, approximately indicated by dotted shading on the map of an extension of about 600,000 km.², besides the small zone 50,000 km.² immediately around the River Plata.

TABLE 13.—*Villa Ortuzar Observatory, Chacarita, Buenos Aires, Lat. 34° 35' 15" S., Long. 58° 28' 15" W. H. 25 mt.*

Average rainfall in mm.

(1901–1920)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	79	66	100	120	72	51	55	57	73	85	100	104	962

Monthly rainfall observed, and deviations from the normal.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1922	Obs.	123	76	74	121	48	101	161	278	53	85	56	19	1195
	Devi.	44	10	—26	1	—24	50	106	221	—20	0	—44	—85	233
1923	Obs.	32	73	135	108	17	60	88	159	53	70	80	101	976
	Devi.	—47	7	35	—12	—55	9	33	102	—20	—15	—20	—3	14
1924	Obs.	56	157	102	19	63	20	3	54	107	15	42	17	655
	Devi.	—23	91	2	—101	—9	—31	—52	—3	34	—70	—58	—87	—307

Notwithstanding that the verification results over the greater area would have improved the percentage, these were not taken into account, so as not to fall into the very common error made by long-range forecasters who claim for verification purposes, atmospheric phenomena occurring over great extensions of territories, and frequently over the whole world.

Table 13 shows the normal rainfall for Buenos Aires for a period of 20 years from 1901 to 1920, and also the monthly values observed during the years 1922, 1923, and 1924 with their corresponding departures from the normal. The year 1924 was very dry compared with the normal, the precipitation being 32 per cent under normal.

With reference to tables 14 to 18, the column headed " Day " indicates the days of the forecast week. As the prediction is issued on Wednesday, Thursday is the first day, Friday the second, etc. In

FIG. 5.—Map showing area used in rainfall verification.

the column headed " o day " are given the cases in which the forecasted rain fell exactly on the day indicated, and in those headed " 1 day," " 2 days," etc., cases when rain fell one day or more before or after the forecasted day.

TABLE 14.—*Verification of forecasted rain for the River Plata Region*

Period June 29, 1922–January 3, 1923

Day		o day	1 day	2 days	3 days	4 days	Sum
Thursday	I	1			1		2
Friday	II	1	1	2	1		5
Saturday	III	1		3		2	6
Sunday	IV	2	2	1			5
Monday	V	4	1	1			6
Tuesday	VI	3	1	1		1	6
Wednesday	VII		1				1
Cases		12	6	8	2	3	31
Per cent		39	19	26	7	10	

It must be remarked that only one case out of 26 was predicted with only one day's anticipation, of the cases within the limit 0-2 days, and the rest prognosticated with 2 to 7 days anticipation in the above period.

In the following period, January to July, 1923, of 34 cases of probable rain within the same limit, only four were forecasted for the first day of the week, and 30 cases with from 2 to 7 days anticipation.

TABLE 15.—*Verification of forecasted rain for the River Plata Region*

Period January 4–July 4, 1923

Day		o day	1 day	2 days	3 days	4 days	Sum
Thursday	I	2	2				4
Friday	II	4	3		1	1	9
Saturday	III	4		1	1	2	8
Sunday	IV	2	1		1	1	5
Monday	V	3		1	2	1	7
Tuesday	VI	2	3	1		1	7
Wednesday	VII	3	1	1			5
Cases		20	10	4	5	6	45
Per cent		44	22	9	11	13	

TABLE 16.—*Verification of forecasted rain for the River Plata Region*

Period July 5, 1923–January 2, 1924

Day		0 day	1 day	2 days	3 days	4 days	Sum
Thursday	I	2		1			3
Friday	II	3		1	1	1	6
Saturday	III	4		2	1		7
Sunday	IV	8	3	1			12
Monday	V	8			1		9
Tuesday	VI	5		1			6
Wednesday	VII	1	1		2		4
Cases		31	4	6	5	1	47
Per cent		66	8.5	13	11	2	

Of the 47 cases of rain predicted for the last half year of 1923, only 3 were forecasted one day in advance and the rest with from 2 to 7 days' anticipation. The majority of the rains fell exactly on the day indicated.

TABLE 17.—*Verification of forecasted rain for the River Plata Region*

Period January 3–July 2, 1924

Day		0 day	1 day	2 days	3 days	4 days	Sum
Thursday	I	2					2
Friday	II	3	1	1	2	1	8
Saturday	III	5	1	1			7
Sunday	IV	4	2		2		8
Monday	V	5	3	2	1		11
Tuesday	VI		2		1	1	4
Wednesday	VII	3	2	1		1	7
Cases		22	11	5	6	3	47
Per cent		47	23	11	13	6	

Of the 47 cases of rain forecasted for the above period, only 2 were predicted one day in advance, and the rest with from 2 to 7 days anticipation.

TABLE 18.—*Verification of forecasted rain for the River Plata Region*

Period July 3–December 31, 1924

Day		0 day	1 day	2 days	3 days	4 days	Sum
Thursday	I	5	2				· 7
Friday	II	4	2	1			7
Saturday	III	13	2				15
Sunday	IV	5		3		1	9
Monday	V	3	2			1	6
Tuesday	VI	2				1	3
Wednesday	VII		1	2			3
Cases		32	9	6		3	50
Per cent		64	18	12		6	

Seven cases of rain in this period were forecasted 1 day in advance, and 43 with from 2 to 7 days' anticipation.

TABLE 19.—*Summary of verification of forecasted rain for the River Plata Region in Per Cent*

Period	0–1 day	0–2 days	0–3 days
June 29, 1922–January 3, 1923............	58	84	91
January 4–July 4, 1923.................	66	75	86
July 5, 1923–January 2, 1924............	75	88	98
January 3–July 2, 1924.................	70	81	94
July 3–December 31, 1924...............	82	94	94
Average per cent........................	70	84	93

TABLE 20.—*Summary of verification of sign of forecasted temperature*

Period	Weeks		Per Cent
	+	—	
June 29, 1922–January 3, 1923...........	18	9	200
January 4–July 4, 1923.................	15	10	150
July 5, 1923–January 2, 1924............	19	8	238
January 3–July 2, 1924.................	19	7	271
July 3–December 31, 1924...............	16	10	160
Average per cent........................			198

The final result of the temperature verification for two and a half years weekly forecasting is, as will be seen in table 20, that the number of weeks with positive correlation as compared with the number of weeks with negative correlation is 198 per cent.

After working some time independently with the weekly weather forecast, the author found that if, as it is intended, the new method of weather prognostication by solar data is going to assist or supplant the primitive and established basis for weather prediction, namely, the daily synoptic weather maps, it is necessary not to make use of these to help the weekly forecast. Therefore the daily weather maps were only consulted a few times during the year 1922 when the difficulties were greater than usual, especially with regards to rain on the first day. Later on this was discontinued, and the weather maps not consulted.

At times it has been a very severe test, but the fact that the daily forecast is in charge of a separate department has made it possible.

As the present paper was intended to show only the verification results for the weekly weather forecast of the " Oficina Meteorologica Argentina," it was not thought advisable to go deeper here into the most interesting point, the discussion of the connection between solar radiation and the various terrestrial phenomena, especially of magnetism and precipitation.

THE MORPHOLOGY OF INSECT SENSE ORGANS AND THE SENSORY NERVOUS SYSTEM

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BUREAU OF ENTOMOLOGY

CONTENTS

INTRODUCTION

There are no facts of structure presented in this paper that are not recorded elsewhere; but a mere lack of new information should not be held to lessen the value of a piece of work, or to make it unworthy of scientific consideration. Facts are the food of science, and, like all food, they do not contribute to growth of the body until digested, distributed, and assimilated.

It is time for entomology to be taking stock of what it has acquired, to assemble its facts, and to get them into form that will facilitate progress, dropping a few old ideas, if necessary, and taking on a few new ones. A science, in its growth, is likely to be something like a caterpillar—it increases rapidly during a period when its skin is soft and elastic, but after a while it begins to become hidebound in its own cuticula; then the old skin must be cast off, and a new one formed that will again allow of growth and development.

A mere review of the known facts on any particular subject, scattered as the records are likely to be through many scientific journals and presented often in highly technical language, may render at least the double service of making the facts more easily available and of showing more plainly the bare spots of ignorance; but it may, also, give an insight into general truths heretofore unrecognized.

Concerning the anatomy of insect sense organs, and the intimate structure of the insect nervous system, much is known, *i. e.*, to those who have studied the sense organs and the nervous system of insects. To the general entomologist, little is known of these subjects. A knowledge of mere structure, however, is of no use in itself, it is only a prerequisite to a study of function. A knowledge of insect physiology, furthermore, is still of no particular importance until it helps us to understand the nature of the insect as a living organism. An understanding of the nature of an insect, again, has real significance only as it enables us to understand the nature of life in general. So, everything we take up in science is of value, in the minds of those to whom a knowledge of the universe is the ultimate aim, only through the superstructure it supports.

To the practical entomologist, however, the value of knowledge may be judged within more finite limits. The acquisition of any information that will help in the control of injurious insect species, or that will further the propagation of useful or beneficial species is to him in itself an end worth attaining. There can be no doubt that the accomplishment of practical results in entomology will be greatly facilitated when we have acquired a better understanding of the physiology, the senses, and the tropisms of insects, and an

insight into how these properties enable insects to maintain so successfully their place in nature in spite of our efforts to dislodge them.

The following résumé, therefore, of the known facts concerning the structure of insect sense organs and the sensory nervous system is offered in the hope that it will be found useful to the experimental worker who is attempting to obtain knowledge of the life processes of insects, with the purpose of rendering practical benefits to mankind from his discoveries, while the generalizations that are suggested from a study of the assembled facts are given as an attempt to further the science of pure morphology.

I. THE NERVOUS SYSTEM OF INSECTS

In complex animals the ectoderm is the body layer that comes into direct contact with the environment. It may be supposed, therefore, that its cells retained from the first a higher degree of the properties of irritability and conductivity than did the cells of those layers that are infolded to form the strictly internal organs. It is not surprising, then, to find that, later, from the ectoderm are developed the sensitive, conductive, and receptor elements of the fully evolved animal.

Insects possess two nervous systems, which, though united with each other in the mature condition, appear to be independent in their origin. One constitutes the *ventral nerve cord* of ganglia and connectives, including the brain; the other consists of the ganglia of the stomodeum and their nerves, forming the *stomatogastric system,* or the so-called " sympathetic " system.

THE ORIGIN OF NERVOUS TISSUE

All true nervous tissue, comprising the nerve cells and their prolongations known as nerve fibers, are formed from the ectoderm. The investing tissue, or neurilemma, may be of mesodermal origin, but some investigators claim that even this in insects comes from the ectoderm.

The ganglia and commissures of the ventral nerve cord arise in the embryo from the ventral part of the germ band. At an early stage of development there appear two longitudinal *neural ridges* (fig. 1 A, *NlR*) on the under side of the embryo, with a median *neural groove* (*NlG*) between them. The ectoderm (*Ect*) both of the ridges and the groove proliferates from its inner surface a layer of large cells, the *neuroblasts* (*Nbl*), which are to generate the tis-

sues of the future ventral nervous system. By multiplication, these
cells form a *lateral cord* of cells in each ridge, and a *median cord*
above the groove. According to Wheeler (1891), there are in insects
typically, as exemplified by the Orthoptera, four rows of primitive
neuroblasts in each ridge, and a median row above the neural groove.
The neuroblasts divide repeatedly, those of the ridges giving rise
to the vertical columns of ganglion cells (fig. 1 B, *GngCls*) that
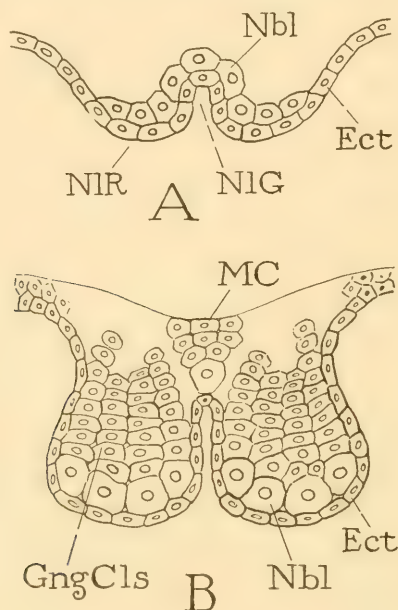
Fig. 1.—Diagrammatic cross-sections of median ventral part of insect
embryo, showing origin of ventral nervous system.

A, formation of neuroblasts (*Nbl*) from ectoderm (*Ect*) of neural
ridges (*NlR*) and neural groove (*NlG*). B, later stage (diagram
based on drawing by Wheeler, 1891) showing formation of median
cord (*MC*) and lateral cords of ganglion cells (*GngCls*) formed from
the original neuroblasts (*Nbl*).

form the lateral cords, those above the groove producing a strand
of cells which is the median cord (*MC*). From these cells are later
formed the cellular and fibrous tissues of the ventral nerve cord.

The ganglia of the stomatogastric nervous system are developed
from the dorsal wall of the stomodeum, which is of ectodermal
origin, but the details of their formation and separation from the
epithelium have not been as fully described as in the ventral ganglia.

An animal with its nervous centers once buried within its body
must establish connections between these centers and its own exterior,

if it is to be aware of what concerns its welfare in the outside world; and it must also have paths of communication from the nerve centers to its muscles and other organs, if it is to control its activities in accord with the information it receives from without. These bonds extending between the nerve centers and the rest of the organism are the *nerve trunks,* which, all together, constitute the *peripheral nervous system.*

THE STRUCTURE OF NERVOUS TISSUE

All nerve fibers are connected with nerve cells; according to the modern conception of the morphology of nervous tissue, nerve fibers are in all cases prolongations of nerve cells. A nerve cell, in the broadest sense, then, consists of the cell body, or *cyton* (fig. 2, *Cy*), together with all of its nerve processes. The entire system is called
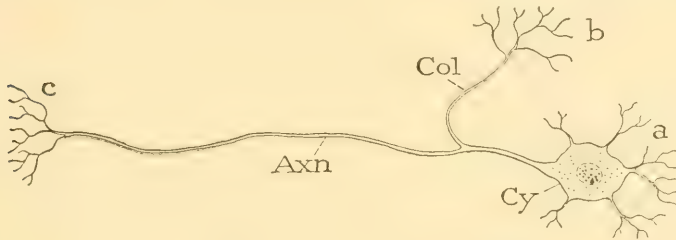
Fig. 2.—Diagram of a nerve cell, or neuron.

a, dendrons; *Axn,* axon; *b, c,* terminal arborization; *Col,* collateral; *Cy,* nerve cell body, or cyton.

a *neuron.* A nerve cyton is said to be unipolar, bipolar, or multipolar, according to the number of processes that arise from it. Of the cell processes, several may be short and branching, but one is usually a long, smooth, continuous axis with few branches. The first are known as *dendrons,* or *dendrites* (*a*), the second is the *axon,* or *neurite* (*Axn*), and constitutes the true nerve fiber from the cell. Branches given off from an axon are distinguished as collaterals (*Col*). The axons, collaterals, and dendrons terminate in fine branches (*b*), often spoken of as *arborizations.*

The principal function of nervous tissue is the transmission of *stimuli.* Stimuli originate either from influences outside the body (sensory stimuli) or from influences within the body. According as the stimuli travel along the nerve fibers toward or away from the nervous centers, the fibers are said to be *afferent fibers* or *efferent fibers.* The fibers which receive stimuli directly, either from without or from within, and transmit them to the nerve centers, constitute the *sensory nervous system.* The efferent nerves and

their root branches, receiving their stimuli secondarily from the central roots of the afferent fibers, constitute what is in general known as the *motor nervous system,* though the out-going stimuli induce not only muscular contraction, but glandular and all other cell activities.

Besides the long nerves that enter or depart from the central ganglia, there are shorter nerves, arising from cytons within the ganglia, that are confined to the limits of one ganglion, and longer nerves which go from one ganglion to another through the commissures. These nerves and their cytons constitute the *association system,* consisting of connective fibers and commissural fibers, which place different parts of the same ganglion, or parts of different ganglia, in communication with one another.

Finally, within the brain, there are two special regions with neurons of their own, which receive association terminals from all parts of the brain and the ventral nerve cord. These regions, known on account of their shape as the *mushroom bodies,* constitute the centers of the entire central nervous system.

The motor nerves are in all cases outgrowths of cells located in the nerve centers. The motor nerve cytons of insects lie either within the ganglia of the brain and the ventral nerve cord, or in the ganglia of the stomatogastric system. The peripheral sensory nerves of most animals, on the other hand, arise from cells lying outside the principal ganglionic centers, which cells either retain a peripheral position or are withdrawn more or less deeply into the body.

In vertebrate animals, most of the sensory cytons are derived from the neural crests of the embryo, ridges of ectodermal cells that are separated from the ectoderm along the line of closure of the neural tube, and which finally come to lie in the spinal ganglia. These cells (fig. 7 B, SCy) send out axons which branch in one direction (SNv) to the outlying parts of the body, and in the other to the spinal cord, thus establishing sensory connections between the peripheral sense receptors of the body wall (BW) and the main nerve centers. Only the nerves of the olfactory organs in vertebrates have their origin in cells that remain permanently in the peripheral ectoderm.

With insects, no neuroblastic cells are known that are analogous to those of the spinal ganglia of vertebrates. The origin and growth of the sensory nerves have not been traced in any insect, but all investigators agree that the sensory nerves end in the central ganglia in finely-branching terminal fibrils (fig. 7 A, SNv), which consti-

tute the sensory neuropiles. This is attested by the works of vom Rath (1896), Kenyon (1896), Jonescu (1909), Haller (1910), Zawarzin (1924), and Orlov (1924).

THE VENTRAL NERVOUS SYSTEM

The lateral cords of the neural ridges of the insect embryo extend from the first segment of the head to the eleventh segment of the abdomen. Each forms a lateral mass of ganglionic cells in each segment, and intersegmental connecting commissures of fibrous tissue between them. Then the ganglionic masses of each segment become united by transverse commissural fibers, forming, in most cases, a compact double ganglion in the segment. The first three
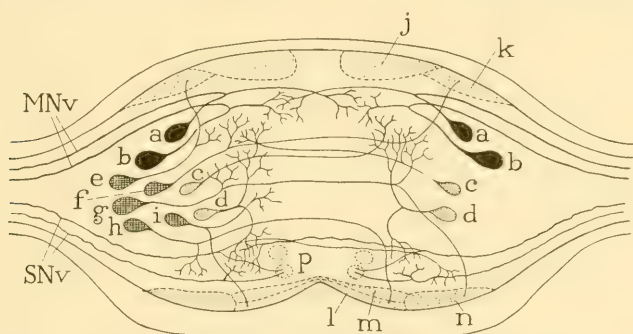
FIG. 3.—Diagrammatic cross-section of an abdominal ventral ganglion (based on diagram by Zawarzin, 1924 a).

a, b, motor cytons; c, cytons of transverse connectives; d. cytons of dorso-ventral connectives; e, f, g, h, i, cytons of longitudinal commissural connectives; j, k, l, m, n, p, dorsal and ventral fibrous tracts of the longitudinal commissures.

primitive pairs of ganglia in the head consolidate to form the *brain,* the next three unite to form the *subœsophageal ganglion;* the last four body ganglia consolidate to form the eighth abdominal ganglion of the adult, the others may remain separate, or they may unite in various combinations. After the formation of the alimentary canal, the brain comes to occupy a dorsal position in the head above the œsophagus, but in its origin it is a part of the ventral nerve cord.

The body ganglia.—In a fully-formed ganglion of the thorax or abdomen the principal cellular elements are arranged peripherally (fig. 3, *a-i*), mostly in the lateral and dorso-lateral parts, while the central and ventral regions are occupied by fibrous tissue, consisting of connective and commissural fibers and the branching roots of sensory nerves and collaterals from motor axons. This fibrous core of the ganglion is known as the *medullary tissue,* or the *punctate sub-*

stance. Within it there are often more or less definite areas formed
by the finely-branching terminals of associated fibers. Such areas
are known as the *neuropiles* of the ganglion. When the fibers of a
neuropile are scattered and the limits of the region are not well de-
fined, the neuropile is said to be diffuse; when the fibers constitute
a definite mass, the neuropile is called a *glomerulus*. In each body
ganglion there is a dorsal motor neuropile region, and a ventral sen-
sory neuropile region.

The principal ganglionic nerves issue as paired lateral trunks
from the sides of each ganglion, but there is often also a posterior,
unpaired, median nerve, which may be continued from one ganglion
to that following. The fibers of the lateral nerve trunks separate
within the ganglion into dorsal and ventral bundles, or *roots*, in
which the fibers of the dorsal roots (fig. 3, *MNv*) are motor axons,
and those of the ventral roots (*SNv*) are sensory axons. This ar-
rangement is just the reverse of that which exists in the spinal
cord of vertebrates (fig 7 B) ; but the main nerve centers of the
Arthropoda and the Vertebrata are developed from opposite surfaces
of the body—they are alike, therefore, in that the sensory roots in
each are those nearest the exterior.

In each body ganglion there are five principal elements: (1) the
cytons and roots of the motor fibers of the lateral nerves; (2) the
roots of the sensory fibers of the lateral nerves; (3) the cytons
and fibers of the intraganglionic connectives; (4) the cytons and
fibers of the longitudinal commissural nerves; (5) the cytons and
roots of the median nerve.

The nerve cytons, or nerve cell bodies, of the motor fibers of the
lateral nerves, according to the diagram of Zawarzin (fig. 3, *a, b*),
lie in the dorso-lateral parts of the ganglion. Each cell gives off a
nerve process which soon divides into two branches. One branch,
the collateral, goes inward and ends with a fine aborization in the
motor neuropile of the ganglion; the other, the axon, turns outward
in the dorsal root of a lateral nerve to become a peripheral motor
fiber (*MNv*). The sensory fibers (*SNv*), coming in from the pe-
riphery, separate from the motor root fibers of the nerve trunk, and
enter the ganglion through the ventral nerve root. Some of the
sensory fibers end in the ventral sensory neuropile of the ganglion;
others merely give off branching collaterals into the sensory neuro-
pile, while the main axon proceeds forward through a longitudinal
commissure to the sensory neuropile of some anterior ganglion.
According to Zawarzin (1924), all the sensory fibers of the ab-
dominal ganglia of a dragonfly larva (*Aeschna*) end in ganglia an-

terior to the one they enter. In the thoracic ganglia, however, Zawarzin says, while the sensory nerves from the body of the segment end in the same manner, *i. e.*, in an anterior ganglion, those from the legs terminate mostly in the ganglia of their respective segments. This evidently has the effect of making each thoracic ganglion a more independent center than are the individual abdominal ganglia.

The intraganglionic connectives in the ganglia of the dragonfly larva, as described by Zawarzin, comprise two sets of fibers and their respective cytons. One set consists of transverse fibers (fig. 3, *c*) which intermediate, by means of basal collaterals and terminal arborizations, between the two sides of the ganglion; the other set consists of T-shaped neurons (*d*), the two branches of which intermediate between the dorsal motor neuropile and the ventral sensory neuropile.

The fibers of the longitudinal commissures have their cytons (*e, f, g, h, i*) in the lateral parts of the ganglion; the axons, after giving off collaterals in the ganglion, proceed through the commissures to other ganglia of the chain. Some of these are motor connectives (*e, f*), sending their collaterals into the motor neuropile of the ganglion; others (*g, h, i*) are sensory connectives, sending their collaterals into the sensory neuropile. Zawarzin distinguishes three types of commissural fibers in the abdominal ganglia of the dragonfly larva: *tautomeric fibers* (*e, i*) that leave the ganglion through the commissure of the same side, after giving off one collateral into this side; *heteromere* fibers (*f, h*) that give off one collateral and then cross to the opposite side of the ganglion to enter the commissure of this side; and *hekateromere* fibers (*g*) that cross the ganglion but give off a collateral in each side.

The commissural tracts pass superficially through the dorsal and ventral parts of each ganglion. Zawarzin distinguishes on each side of the dorsal part of each ganglion in the dragonfly larva a median tract (fig. 3, *j*) which contains fibers that go long distances through the nerve chain, and a lateral tract (*k*) that contains the shorter dorsal fibers; and, on each side of the ventral part, an external median tract (*l*) of long fibers, an internal median tract (*m*) of short fibers, and a lateral tract (*n*) of short fibers. Besides these, finally, he says there are two internal ventral tracts (*p*) on each side that contain the sensory fibers which traverse the commissures.

The cytons and roots of the median nerves of the ventral ganglia, according to Zawarzin, lie in the posterior parts of the ganglia; but we are not here concerned with these nerves.

The brain and its nerves.—The brain of an insect consists of the ventral ganglia of the first three head segments united into one

mass. The first pair of ganglia constitutes the *protocerebrum* (fig. 4, *1Br*), the second the *deutocerebrum* (*2Br*), and the third the *tritocerebrum* (*3Br*). The transverse commissures of the first and second pair form fibrous tracts (*1Com, 2Com*) within the brain, but the connectives of the tritocerebral ganglia (*3Com*) form an independent commissure beneath the œsophagus (*Œ*). The trito-cerebral ganglia, therefore, really belong to the post-oral series of ganglia.
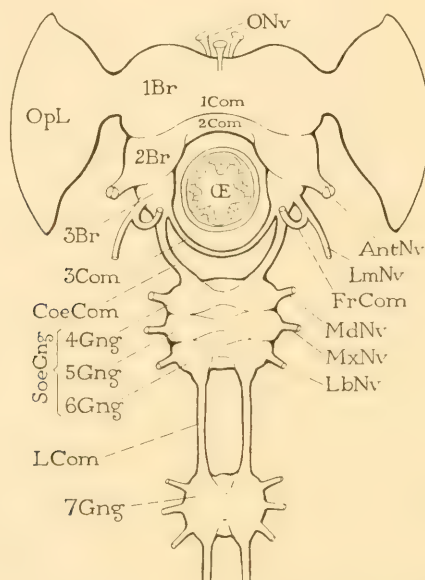
FIG. 4.—Diagrammatic structure of brain and subœsophageal ganglion.

The brain consists of the protocerebral (*1Br*), deutocerebral (*2Br*), and tritocerebral ganglia (*3Br*), the first two connected by transverse commissures (*1Com* and *2Com*) above the œsophagus, the third by a commissure (*3Com*) beneath the œsophagus. The subœsophageal ganglion (*SœGng*) consists at least of the united fourth, fifth and sixth head ganglia, with nerves to the mandibles, maxillæ, and labium, and with other nerves from its posterior part (not shown).

In the brain, the same essential elements are to be found that are present in the ganglia of the ventral cord, except that in it cells of longitudinal commissural fibers have not been distinguished as such. The internal structure of the brain, however, in the higher insects, is far more complicated than that of a ventral ganglion, first, because of the composit nature of the brain, second, because of the presence of the great sensory tracts of the eyes and the an-tennæ, and third, on account of the development of the *corpora pedunculata,* or so-called *mushroom bodies,* in which there come

together association fibers from all parts of the brain and the ventral cord.

The mushroom bodies, apparently, have no counterparts in any of the ganglia of the ventral cord. Each consists of a double fibrous *stalk* (fig. 5, *b*), buried in the lateral lobe of the protocerebrum, and of two cup-like fibrous masses, the *calyces* (*a, a*), supported on the ends of the stalks in the dorsal part of the brain. The calyces are filled with nerve cells (*c*), the axons of which (*f*) penetrate the stalks of the bodies and give off finely-branching collaterals (*e*) into the tissue of the calyces. At the lower end of the stalk of each body the fibers separate into a ventral and an anterior root. The mushroom bodies receive association fibers (*d*) from
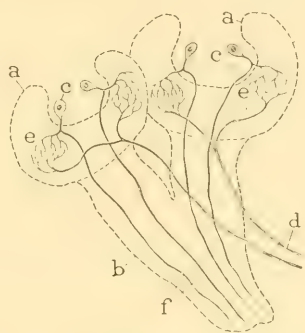
Fig. 5.—Diagram of a " mushroom body," or corpus pedunculatum, of the brain.

a, a, calyces; *b,* stalk; *c,* calyx cells giving axons (*f*) into the stalks, and collaterals (*e*) into the neuropiles of the calices; *d,* association fibers from other parts ending in arborizations within the calices.

nearly all other parts of the brain, from the suboesophageal ganglion, and from the other ganglia of the ventral nerve cord, most of which end in fine branches within the calyces. If the insect, therefore, has intelligence, or consciousness of external things that affect it, or of its own actions, the seat of this faculty must surely be in the mushroom bodies. Or, if insects are but living mechanisms, the chief regulatory centers must again be these bodies, which are to the ganglia what the ganglia are to the peripheral nerves—they are the centers of the central nervous system. The mushroom bodies appear to be present in nearly all insects, but they are much more highly developed in the Diptera and Hymenoptera than in the lower orders.

The first division of the brain, the protocerebrum (fig. 4, *1 Br*), supports the simple and the compound eyes, but a discussion of the optic tracts and the ocellar nerves is omitted here because the

structure of the organs of vision will be but briefly treated in this paper. The protocerebral segment of the head has no true appendages, and there are probably no muscles innervated from the protocerebrum. Therefore, this part of the brain contains few motor cytons. Kenyon (1896) says there are motor fibers in the ocellar nerves of the honeybee, but he believes that they regulate the activities of the pigment in the ocelli.

The deutocerebrum, or second division of the brain (fig. 4, *2Br*), consists mostly of the large antennal lobes and the fibrous tracts of the deutocerebral commissure (*2Com*). The appendages of the deutocerebral head segment are the antennæ. These organs in insects are highly sensitive structures, being provided with sense receptors of many different kinds. They are also delicately mobile, and are responsive to subtle influences from all parts of the body. Each contains muscles that move its flexible parts, while the appendage is moved as a whole by muscles within the head inserted upon its base. Each antenna is transversed by a nerve trunk, commonly double, which contains, at least in its proximal part, both sensory and motor fibers, and each trunk gives off from its base a motor branch to the antennal muscles of the head. The roots of the antennal nerves lie within the antennal lobes of the deutocerebrum.

The motor cytons of the antennal nerve, according to Jonescu (1909), in the honeybee, are arranged in two groups corresponding with the two divisions of the nerve trunk, one group being in the upper part of the antennal lobe, the other in the ventral part. Kenyon (1896) says that collaterals from some of the motor axons branch upon the bases of the mushroom bodies, but that the majority of them go backward to the tritocerebral region of the brain and to the subœsophageal ganglion, where they come in contact with nerve ends from this ganglion and from the ventral cord. The motor cytons thus mark the roots of the antenno-motor fibers as belonging to the deutocerebrum; but the stimuli received by the fibers may come from all possible sources.

The sensory antennal fibers end in fine branches within neuropile bodies, or glomeruli, of the antennal lobes. These bodies contain also the end branches of connective fiber collaterals, the principal axons of which go to the mushroom bodies, in the calices of which they break up into terminal aborizations. Here these fibers come into close relation with the branches of the mushroom body nerves themselves, and with the terminations of all the other nerves that center in these bodies. The sensory stimuli received by the antennæ may thus be transmitted to motor nerves going out to all

parts of the body. The similarity of the glomeruli of the antennal lobes of insects to those of the olfactory lobes of a vertebrate brain has strengthened the idea that the sense receptors of the antennæ are chiefly organs of smell.

The third division of the brain consists of the tritocerebral ganglia (fig. 4, *3Br*), but since the connecting commissure (*3Com*) lies beneath the œsophagus, these ganglia do not form an intimate part of the brain. The tritocerebral segment of the head has a pair of vestigial appendages in the embryonic stage of some insects, but the appendages disappear in all adult insects, except possibly in *Campodea,* one of the Thysanura. Each tritocerebral lobe gives off two nerves, a labral nerve (*LmNv*) and a frontal ganglion nerve, or frontal commissure (*FrCom*), but the two are usually united at their bases into one labro-frontal, or tritocerebral, nerve trunk. The labral nerve innervates the labrum and some of the dorsal muscles of the pharynx. It is said to be composed of sensory fibers, the roots of which, according to Jonescu (1909), in the honeybee, are distributed in the protocerebrum, within and beneath the deutocerebral commissure, and in the antennal lobes. Kenyon (1896) says that some of its roots go also into the subœsophageal ganglion. The frontal commissure is said to consist of motor fibers, the cytons of which lie in the tritocerebral lobes.

The subœsophageal ganglion.—The composit ganglionic mass lying in the lower part of the head, known as the subœsophageal ganglion, (fig. 4, *SœGng*) on account of its position below the œsophagus, consists at least of the united ganglia of the fourth, fifth, and sixth head segments (*4Gng, 5Gng, 6Gng*). Its principal nerves innervate the mandibles, the maxillæ and the labium, but besides the three pairs of mouth part nerves there is commonly a fourth pair, and sometimes several pairs, issuing from the posterior part of the ganglion. One of these posterior nerve pairs has been traced in some insects to the salivary glands; the others when present go to the neck region and into the prothorax. The origin of nerves other than those of the mouth parts from the subœsophageal ganglion might suggest that this ganglion is a composit of more than three primitive ganglia, and Verhoeff (1903) has argued that here is positive evidence of the presence formerly of a neck segment, or "microthorax," in insects, homologous with the segment of the poison fangs in the Chilopoda, the ganglionic center of which is united with the ganglia of the true mouth part segments. Ontogeny, however, has not recorded the presence of a neck segment rudiment in any insect embryo, and entomologists mostly still re-

gard the sclerites of the neck in insects as secondary developments. Likewise, embryology has not demonstrated a fourth component in the insect subœsophageal ganglion. Verhoeff's idea of the quadruple structure of this ganglion should not be confused with the claim, now pretty well discarded, that the ganglion comprises a pair of ganglionic centers between those of the mandibles and the maxillæ, innervating the lateral lobes (superlinguæ) of the hypo-
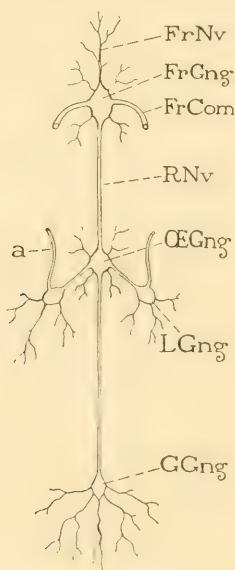
Fig. 6.—Diagram of a typical arrangement of ganglia in the stomatogastric nervous system.

FrGng, frontal ganglion, connected with tritocerebrum by frontal commissures (*FrCom*) and giving off posteriorly the recurrent nerve (*RNv*) to œsophageal ganglion (*ŒGng*); the latter connected by lateral nerves with lateral ganglia (*LGng*), each of which is united with back of brain by small nerve (*a*), and by median nerve with gastric ganglion (*GGng*).

pharynx. A more detailed investigation of the internal structure of the subœsophageal ganglion, which has been less studied than that of the brain or the body ganglia, should be made before any definite statement can be given of the exact composition of the ganglion or the homologies of its posterior nerves.

THE STOMATOGASTRIC NERVOUS SYSTEM

The ganglionic centers of the stomatogastric nervous system are located on the dorsal surface of the stomodeal parts of the alimentary canal, from the epithelium of which they are formed in

the embryo. The number and arrangement of the ganglia differ much in different insects, but a typical scheme of the ganglia and the principal nerves of this system is shown diagrammatically in figure 6. The most anterior ganglion is the median *frontal ganglion* (*FrGng*), situated on the dorsal wall of the pharynx before the base of the brain. It is united laterally by the *frontal commissures* (*FrCom*) with the tritocerebral regions of the brain, as already described (fig. 4). Anteriorly it gives off a small median *frontal nerve* (*FrNv*) with branches to the pharynx and the clypeal region of the wall of the head. Posteriorly a median *recurrent nerve* (*RNv*) goes back from the ganglion beneath the brain to a second median ganglion on the pharynx below or behind the brain. This ganglion is known as the *œsophageal ganglion* or *hypocephalic ganglion* (*ŒGng*). From it is given off on each side a short nerve to a *lateral ganglion* (*LGng*) located on the dorsolateral part of the pharynx or œsophagus (the " œsophageal ganglion " of Berlese). Each of these lateral ganglia is connected with the posterior part of the brain by a small nerve (*a*). The median œsophageal ganglion may also give off posteriorly a long median nerve which ends in a gastric ganglion (*GGng*) on the wall of the stomach. Besides the main nerve trunks, many smaller nerves arise from all the ganglia of the stomatogastric system, which are mostly distributed on the stomodeal and ventricular parts of the alimentary canal, but some go to the walls of the head, the surface of the brain, to the aorta, and to other neighboring organs.

Janet (1899) has proposed the interesting theory that the three median ganglia of the stomatogastric chain are the primitive ventral ganglia of three pre-cerebral segments that have been invaginated to form the stomodeum. This theory, however, must assume first that, prior to the stomodeal invagination, the first six pairs of ventral ganglia migrated upward in the sides of the body and then came together dorsally, the two ganglia of each segmental pair uniting above the alimentary canal. Then, with the retraction of the supposed stomodeal segments, the three pre-cerebral ganglia were drawn inward with their segments, the first one becoming the gastric ganglion, the third becoming the frontal ganglion. Next, the theory must assume that the posterior roots of the frontal-protocerebral connectives became shifted from the protocerebrum to the tritocerebrum; while, finally it assumes that the transverse commissures of the stomatogastric ganglia have been lost, and that those of the brain ganglia are all united in the suboesophageal commissure. None of these assumptions is supported by the known

facts either of the development or of the structure of the parts
concerned. The median ganglia of the stomatogastric system, more-
over, are so variable in number that the scheme given above can
scarcely be regarded as representing a primitive arrangement. The
frontal ganglion is the only one of constant occurrence; one or
both of the other median ganglia may be lacking. The lateral
ganglia must in any case be regarded as of secondary origin. They
are apparently always connected with the median system, but each
has also one or two connectives with the back of the brain. In
caterpillars the lateral ganglia are entirely separated from the walls
of the alimentary canal, and their principal nerves go to muscles
of the anterior dorsal and lateral parts of the head.

According to the accounts of Zawarzin (1916) and Orlov (1924),
the nerves of the stomatogastric system contain both motor fibers
and sensory fibers, the former having their cytons in the ganglia,
the latter arising from cells distributed over the innervated parts
of the alimentary canal and ending in fine terminal arborizations
within the ganglia.

THE ORIGIN OF THE SENSORY NERVES

Since no sensory cytons have been found in the central gan-
glia of insects, or anywhere associated with them, students of the
central nervous system follow vom Rath (1896) in insisting that
the generative cells of the sensory nerves must be found in the
periphery, presumably in the ectodermal tissue of the body wall
and the alimentary canal.

When the sensory fibers are traced outward from the central
ganglia, each is found to end in a cell. Some of the cells are
bipolar, others are multipolar. The distal process of some of the
bipolar cells goes direct to a sense organ of the ectoderm, either
one in the hypodermis, or one in the epithelium of the alimentary
canal. Bipolar cells of this kind, connected with specific sense
organs, constitute the sensory cells of Type I of Zawarzin (1912 a).
The other cells, which may be either bipolar or multipolar, but
which are characteristically multipolar, give off terminal processes
that end in fine branches on the inner surface of the hypodermis,
perhaps also on the tendons of the skeletal muscles, and on the walls
and muscles of the alimentary canal. Cells of this kind constitute
the sensory cells of Type II of Zawarzin. The cells of both types
lie either within or just beneath the ectodermal tissues they inner-
vate, and they are the only cells yet found in the courses of the
sensory nerves. This has given rise to the idea that they are the

true cytons of the sensory fibers, according to which, all the sensory nerves of insects are analogous to the olfactory nerves of vertebrates, being the centripetal axons of nerve cells developed in the peripheral ectoderm.

The developmental origin of the sensory cells of Type I that lie within the hypodermis has been studied by many investigators, and all agree that they are specialized hypodermal cells. No one has demonstrated the growth of a nerve axon from these cells, while, on the other hand, several investigators have claimed that a nerve fiber grows outward and unites with the sense cell. Berlese (1909), for example, after studying the postembryonic develop-
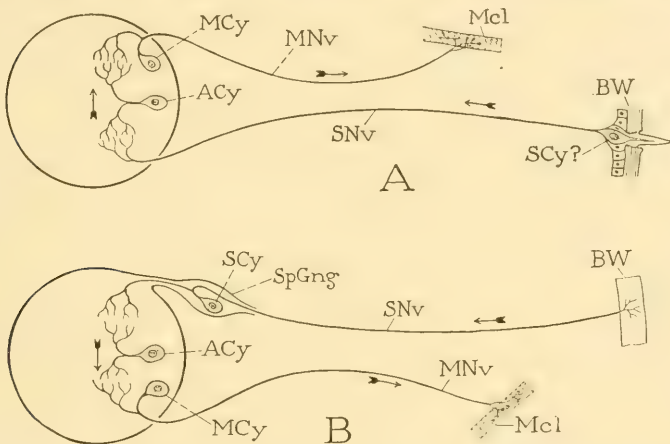
Fig. 7.—Comparative diagrams of central and peripheral nervous systems of an insect (A) and a vertebrate (B). In the vertebrate most of the sensory cytons (*SCy*) are in the spinal ganglia (*SpGng*); in the insect the apparent sensory cytons (*SCy?*) are in the hypodermis.

mental stages of several kinds of sense organs, says that, in all cases, it is found that a sensory nerve proceeds outward from the central nerve chain and elongates until it attains the basement membrane of the body wall at the point where the sense organ is to be formed. Here it remains until the sense organ is ready to receive it, when it penetrates the basement membrane and unites with the sensory complex that has formed in the hypodermis. Vogel (1923) says that in a mature larva of a wasp the antennal nerve has already reached the tip of the antenna without penetrating the basement membrane of its walls. During an early stage of the pupa, however, branches of the nerve enter the hypodermis, where a single fiber unites with the base of each sense cell. The base of the sense cell, Vogel says, may elongate slightly toward the nerve, but the connection with

2

the latter is made in the immediate neighborhood of the cell. From his observations, made on specimens stained by the Golgi method, Vogel claims that the antennal nerve of insects is not to be likened to the olfactory nerve of vertebrates, and that the innervated cell of an insect sense organ becomes secondarily a sense cell by union with a sensory nerve fiber.

It still, therefore, appears to be true, as Berlese (1909) has said, that those writers " who had hoped for a demonstration of the hypodermal cells themselves becoming ganglion cells, have awaited in vain that this should be proved." Yet, Vogel's conclusion that there must be found in the deutocerebrum a ganglionic center from which the sensory antennal nerves take their origin, has also not been substantiated, for the elaborate studies of vom Rath, Kenyon, Haller, and Jonescu have failed to reveal anywhere within the central ganglia of insects the cytons of the sensory fibers. Perhaps they lie somewhere between the extreme periphery and the nerve centers. The subject of the origin of the sensory nerves in insects or other invertebrates is one on which the embryologists are strangely silent, and until further investigations shall give us more light upon it, we cannot reconcile the two apparently contradictory sets of observations. Either the claims from one side or the other are incorrect, or there is some undiscovered source of the sensory axons, possibly corresponding with the neural crests of the vertebrate embryo.

II. THE PERIPHERAL ENDINGS OF THE SENSORY NERVES

Some nerve trunks consist entirely either of motor or of sensory fibers; but, for the most part, the two kinds of fibers, after leaving the central ganglia, are bound together in the same nerve trunks. Toward the periphery, however, the two sets of fibers again separate, and individual axons proceed to their own destinations.

The peripheral ends of the sensory fibers, as we have already seen, end in bipolar or multipolar cells, the distal processes of which either go direct to specific ectodermal sense organs, or they break up into fine branches beneath the hypodermis and on the wall and muscles of the alimentary canal. The bipolar cells with unbranched distal processes going to the external sense organs are distinguished, according to the classification of Zawarzin (1912 a), as sensory cells of Type I; the bipolar and multipolar cells, with branching terminals or dendrons, as sensory cells of Type II. Since the former belong to the cellular complexes of the sense organs they will be

described in following sections of this paper treating of the general and specific structure of the sense organs; this section will deal with the cells of Type II.

For convenience of description, the sensory nerve endings of the body wall, and those of the alimentary canal will be described under separate headings. Nearly all the axons of the nerve endings of the body wall proceed to the ganglia of the ventral nervous system; those of the alimentary canal go both to the ventral ganglia, and to the ganglia of the stomatogastric system.

FIG. 8.—Peripheral endings of sensory nerves on inner surface of hypodermis.

A, a subhypodermal multipolar sensory nerve cell of Type II (*CyII*) of a dragonfly larva with branches on articular membrane between trochanter and femur (Zawarzin, 1912). B, part of subhypodermal network of nerves from cells of Type II in larva of *Melolontha* (Zawarzin 1912 *a*).

THE SENSORY INNERVATION OF THE HYPODERMIS

In many soft-bodied larvæ of insects there is an extensive network of nerves on the inner surface of the hypodermis, which is formed by the finely-branching terminals of the bipolar and multipolar peripheral sensory cells of Type II. This network (fig. 8 A, B) constitutes the so-called *subhypodermal plexus,* though the fibers composing it probably do not unite with one another.

The extent to which this hypodermal innervation occurs in different insects, especially in adults, has not been determined; it is known to exist chiefly in soft-skinned larvæ. A subhypodermal nerve net was first noted by Viallanes (1882) in the larvæ of Diptera (*Stratiomys, Eristalis, Musca*). It was described later in more detail by Monti (1893, '94) in the larvæ of Cerambycid beetles, by Holmgren (1896) in the caterpillar of *Sphinx ligustri,* by Hilton (1902) in the silkworm, and finally by Zawarzin (1912 *a*) in the larva of *Melolontha*

vulgaris (fig. 8 B). Zawarzin (1912) says also that there are branching nerve fibrils in some places beneath the membranous parts of the cuticula in dragonfly larvæ (fig. 8 A), and Monti reports the presence of a rich arborization of nerve fibers arising from multipolar cells on the inner surface of the hypodermis in adult Orthoptera. Several writers have described a nerve net beneath the body wall of other arthropods; Bethe (1896), for example, found it in the freshwater crayfish, Němec (1896) in land isopods, where, he says, the nerve endings lie between the hypodermal cells, and Holmgren (1896) reports a plexus similar to that of insects in various groups of Crustacea.

The writers mentioned above all assert that the cells of the subhypodermal net are nervous elements, but Duboscq (1897) claims that similar cells present in Forficulidæ are connective tissue cells, and he discredits the idea that the cells are in any case nerve cells. All studies of the subhypodermal network and its cells have been made by the methylenblue method of staining nerve tissues.

The most concise account of the subhypodermal innervation of an insect is that by Zawarzin (1912 *a*) made on the larva of *Melolontha vulgaris*. Beneath the skin of the larva, Zawarzin says, there is a finely-branching system of nerve fibrils forming a network of large and small meshes over all parts of the body (fig. 8 B), including the appendages, but particularly developed on the middle of the back. The nerves (*Nv*) that break up to form the net proceed from small, irregular cells of Type II (*CyII*), some bipolar, other multipolar. The distal processes of the cells branch dichotomously into the fibrils of the larger meshes, and these ramify to form the threads of the finer meshes. None of the fibrils, Zawarzin says, unite with one another, though they often appear to do so when they lie close together. Monti noted the same in studying the subhypodermal nerve net of Cerambycid larvæ. The fibrils of the larger meshes in *Melolontha* are relatively smooth, but the finer branches are characteristically varicose, presenting numerous small swellings along their courses. All investigators have noted this varicosity of the end branches of the subhypodermal nerves of insects, and the same feature is described for the branches and fibrils of the sensory nerves in the human epidermis. The actual endings of the fibrils in insects have not been definitely observed, but the terminal branches appear to end free on the basement membrane.

The character of the fibrils in the subhypodermal nerve net apparently leaves no doubt that they are the terminals of sensory nerves, since the fibrils of the sensory roots in the central ganglia have the

same varicose structure. It is reasonable to suppose that they are sensitive to external stimuli, to mechanical stimuli, at least, and possibly to changes of temperature. Sparsely-haired caterpillars react to gentle pressure on the skin between the tactile hairs, and naked, soft-bodied larvæ are well known to be highly sensitive to touch anywhere on the body surface, showing that a sense of touch is not dependent on the presence of special tactile organs. Viallanes noted that naked fly larvæ possess peripheral cells of Type II, though lacking those of Type I which innervate the body hairs of other species. Since the nerve endings of cells of Type II, however, are apparently all alike, and are not associated with specialized cells of the hypodermis, it may be questioned whether they receive differentiated sensations. Possibly, perceptions received through them, whether of mechanical, thermal, or chemical stimuli, are merely general sensations akin to degrees of pain.

It is suggested by Orlov (1924) that the skeletal muscles of insects receive a sensory innervation through their tendons from the subhypodermal nerves. Orlov, however, remarks that there is no literature on the sensory nerves of the skeletal muscles of invertebrates, except for the negative statement of Döflein that no such nerves are present in the Arthropoda.

The peripheral sensory cells of Type I, the single distal processes of which are non-varicose, non-branched, and go direct to the tactile hairs or other cuticular sense organs, are associated with the cells of Type II in hairy larvæ, since they commonly lie beneath the hypodermis, more or less removed from the bases of the sense organs. These cells are usually larger than the others, and have more regular, oval, or fusiform shapes (fig. 11, *SCl*). The sense cells of adult insects generally lie within the hypodermis (fig. 12) and, in their origin, are clearly modified hypodermal cells. The subhypodermal sense cells of larval insects, and the intrahypodermal sense cells of adults are possibly not of the same origin, but on this subject we have no light at present.

THE SENSORY INNERVATION OF THE ALIMENTARY CANAL

There are only two papers, known to the writer, treating of the sensory nerves of the alimentary canal in insects, and the endings of the nerves in the various tissues of the tract. One of these is by Zawarzin (1916), describing the stomatogastric system of *Periplaneta americana;* the other is by Orlov (1924) on the innervation of the alimentary tract of Lamellicorn beetle larvæ.

In the cockroach, as described by Zawarzin, there are numerous sensory nerve cells of Type II, mostly multipolar, distributed over the walls of the crop. Some of these cells lie free on the outer surface of the epithelium, some are more or less inclosed within the nerve trunks, and others lie beneath the covering membranes of the ganglia. The distal processes of the free cells break up into fine varicose fibrils that terminate between the epithelial cells; the distal processes of the other cells apparently innervate the neurilemma of the nerves and ganglia. The main axons, in all cases, go to the principal stomatogastric ganglia where they terminate in neuropile arborizations. Zawarzin does not describe sensory nerves ending in the muscles of the crop.

The alimentary canal of larvæ of Lamellicorn beetles, as described by Orlov, is innervated both from the stomatogastric system and from the abdominal ganglia of the ventral nerve cord. In the larvæ of *Oryctes* and *Melolontha,* there is a nerve ring around the posterior end of the œsophagus, connected by lateral nerves with the œsophageal ganglion, from which six equally spaced, parallel nerve trunks go posteriorly on the walls of the ventriculus. From the ganglia and from the nerve trunks there are given off numerous ramifying nerve branches, containing both motor and sensory fibers, that spread over all parts of the œsophagus and stomach.

The sensory fibers, Orlov says, end peripherally in multipolar nerve cells, the terminal processes of which branch into a network of fine varicose fibrils similar to the sensory network beneath the hypodermis. The fibrils terminate on the œsophagus and the ventriculus, some in the connective tissue, and some in the sarcolemma of the muscle fibers. Several types of nerve endings on the muscles are distinguished by Orlov. In typical cases, a nervous network surrounds the muscle fiber, and the nerve fibrils contain flat swellings from which are given off fine varicose terminal threads with free ends (fig. 9 A) ; in other cases, the nerve fibers end directly in varicose branches on the muscles (B) ; while, again, the nerve may make a complicated spiral tangle about the muscle fiber (C). In most cases, the branches of one sensory nerve cell are localized on one fiber, but in some they spread over adjoining parts of several fibers (B). The character of the sensory endings always distinguishes them from the endings of the motor fibers.

The proctodeum of Lamellicorn larvæ, according to Orlov, is innervated by abdominal ganglia of the ventral nerve cord, from which it receives both motor and sensory fibers. On the small intestine the sensory fibers are distributed principally on the connective tis-

sue layers surrounding the epithelium and uniting the muscles. The rectal sac has no sensory innervation, but the posterior straight part of the rectum is provided with sensory networks of varicose fibers, arising from multipolar cells, lying between the epithelium and the muscular coat, and on the outer surface of the latter. On the terminal part of the rectum, Orlov notes, besides these cells of Type II, also bipolar cells of Type I, the distal processes of which go to sense organs in the rectal wall (fig. 22).

The brief descriptions of the sensory nerves given in this section summarize practically all that is known of the sensory innervation of insects. It is evident that much must yet be done in this field before we can pretend to have anything approximating a comprehensive
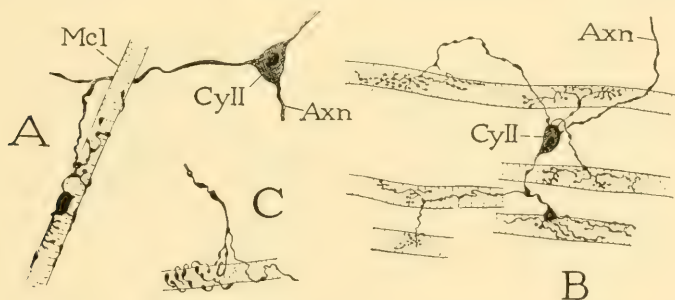
Fig. 9.—Various types of sensory innervation of muscles of alimentary canal of Lamellicorn beetle larvæ by nerves of stomatogastric system (Orlov, 1924).

A, B, from œsophagus of larva of *Oryctes*. C, from ventriculus of larva of *Melolontha*.

knowledge of the subject, and we should feel grateful to the few workers who have contributed what information we now possess.

III. THE GENERAL STRUCTURE AND CLASSIFICATION OF INSECT SENSE ORGANS

The true sense organs of insects are more or less complex structures formed, in all cases, from a part of the body wall. Usually there is a specialized cuticular element having the shape of a hair, peg, dome, plate, or lens, and there are always cellular elements consisting of specialized hypodermal cells, of which one at least is connected with the end of a sensory nerve. Any study of the structure of insect sense organs must, therefore, be based on an understanding of the general structure of the body wall and the particular structure of its cuticular appendages.

THE STRUCTURE OF THE BODY WALL AND ITS APPENDAGES

The foundation of the body wall is the ectodermal layer of cells commonly known in insect anatomy as the *hypodermis* (fig. 10 A, *Hy*). The cells are lined on their inner surfaces by the *basement membrane* (*BM*), which is either a homogeneous product of the cells themselves, or is perhaps itself, in its origin, a cellular tissue derived from the mesoderm. The outer surface of the hypodermal layer is covered by the *cuticula* (*Ct*), a secretion from the cells containing chitin as its characteristic component. In sections, the cuticula usually shows a horizontally lamellate structure, and a differentiation into an outer denser part, the *epidermis,* or *exocuticula* (*Epd*), and a clearer, softer internal part, the *dermis,* or *endocuticula* (*Dm*).
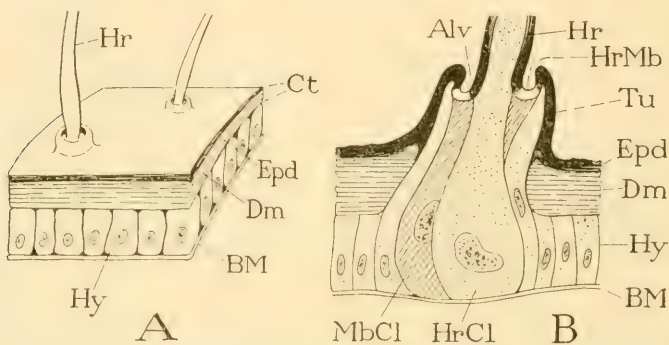
FIG. 10.—Diagrammatic structure of the body wall, and of a tuberculate hair, or seta.

A, piece of body wall bearing two setæ. B, section of base of a seta showing two cells associated with it, the seta-forming cell, or trichogenous cell (*HrCl*), and the cell of the hair membrane (*MbCl*).

The commonest types of external appendages of the body wall have the form of hollow hairs or *setæ*. A seta (fig. 10 B, *Hr*) is an outgrowth of the cuticula formed by a large hypodermal cell, known, on account of its special function, as a *trichogenous cell*, or *trichogene* (*HrCl*). The base of the seta is commonly attached by a membranous ring, the *hair membrane* (*HrMb*), to the surrounding cuticula. Sometimes the hair stands on the surface of the body wall, but more usually it is sunken into a cup or *alveolus* (*Alv*). The rim of the alveolus may be flush with the general cuticular surface, or it may be elevated to form a *tubercle* (*Tu*) supporting the hair base.

Beneath the hair and its membrane there is a large cavity in the cuticula, open proximally, but distally prolonged into the hollow of

the hair. This cavity is known as the *hair canal,* or *pore canal.* The hair canal is usually occupied by the outer ends of several cells that have formed the distal cuticular parts. One of these is the trichogene, another is the formative cell of the hair membrane, the *membrane cell (MbCl),* while others are unspecialized hypodermal cells of the canal wall, being more prominent where the hair is situated on a tubercle (fig. 11, *b*). The distal end of the membrane cell normally surrounds the neck of the trichogene at the base of the hair, though after the hair is formed at any molt the trichogenous cell may withdraw from the seta and retract from its base, leaving a vacuole beneath the seta (fig. 12, *Vac*). Especially is this true in the adult stage.

The various cells associated with the hair are not always easily distinguishable in sections, and they have not always been included in descriptions and figures of the cuticular organs; yet, theoretically, we must assume that they are present, in most cases, though perhaps variously modified. It is especially important to take them into account, particularly the hair cell and the membrane cell, in any study of the morphology of insect sense organs.

SENSORY HAIRS

A seta sensitized by a nerve connection is the commonest form of insect sense organ. The innervation is always through a special bipolar sense cell, the proximal process of which is continuous with a sensory nerve, while the distal process is associated with the seta. In adult insects the sense cell is situated within the hypodermis (fig. 12, *SCl*), being limited internally by the basement membrane, though its size or position may cause it to project into the body cavity beyond the general level of the hypodermis (fig. 13 B). In some larval insects, on the other hand, the sense cell may lie beneath the hypodermis (fig. 11, *SCl*) some distance removed from the base of the cuticular organ, with which it is connected by a long distal process (*d*) that penetrates the basement membrane (*BM*). The sense cells of adult insects are unquestionably modified hypodermal cells; the origin of the larval sense cells that lie beneath the hypodermis has not been determined. The two sets of cells will, most likely, prove to be homologous, for Zawarzin (1912 *a*) notes that the sense cells of the sense organs of Lamellicorn beetle larvæ lie in some cases within the subsetal canal, in others in the hypodermis, and in others beneath the hypodermis; but, for the present, we apparently must distinguish between *intrahypodermal* sense cells, and *subhypodermal* sense cells. The latter constitute the subhypodermal sensory cells of Type I, already noted.

Sensory hairs with subhypodermal sense cells.—A good description of the structure of a setal sense organ innervated through a subhypodermal sense cell may be found in the recent paper by Schneider (1923) on the sense organs of the cabbage worm (*Pieris brassicæ*). The body of the caterpillar, according to Schneider, is covered by small tuberculate hairs, all of which have sense cell connections. Beneath the hair is a large trichogenous cell (fig. 11, *HrCl*), with a large bent nucleus in its base, and having its distal end prolonged into the hollow of the seta (*Hr*). Attached distally to the hair membrane (*HrMb*) is a membrane cell (*MbCl*) which surrounds the neck of the hair cell, and is continued to the basement
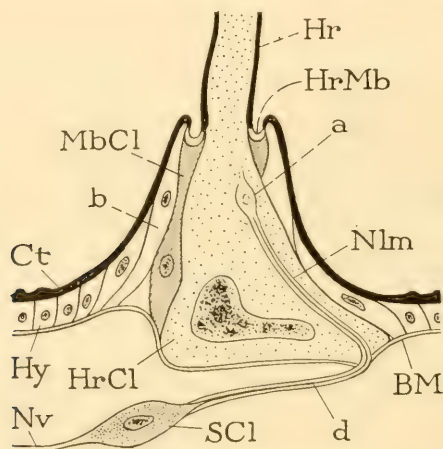
Fig. 11.—Example of the innervation of a larval tactile hair through a subhypodermal sense cell. (Section of a body hair of a cabbage worm, diagrammatic from Schneider, 1923.)

membrane at one side of the hair cell. Several other hypodermal cells (*b*), belonging to the walls of the tubercle, surround the trichogene and the membrane cell. Since the hairs are renewed with each molt, and are increased in size, the trichogenous cells vary in size and contents according to the period in each instar, becoming large and full before the molt, and shrinking following the molt. New hairs, also, are added with each renewal of the cuticula.

A bipolar sense cell (*SCl*) lies beneath the hypodermis in the immediate neighborhood of each seta, and sends a long, slender distal process (*d*) through the basement membrane (*BM*), along the side of the trichogenous cell, toward the base of the hair. Presumably, the process ends on the base of the hair, but Schneider says that he failed to find its exact termination, though it never penetrates

beyond the base of the hair. The process has a subterminal swelling
(*a*) which contains a dark nucleus-like body. Whether this body be-
longs to the cell process, or is a nucleus of the neurilemma investing
the latter was not determined, but Schneider points out that the
swelling is *not* the sense cell of the organ, though some writers have
described it as such.

Other writers, Viallanes (1882), Monti (1893, 1894), Hilton
(1902), Zawarzin (1912 *a*), and Orlov (1924), have given essen-
tially the same account of the subhypodermal sense cells in larval
insects, but with less detail as to the structure of the sense organs
with which they are connected.
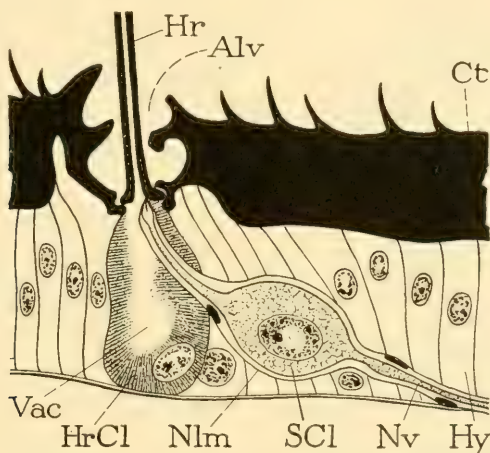
FIG. 12.—Example of a tactile hair innervated through an intrahypo-
dermal sense cell. (Section of a hair on the cercus of an adult cricket,
Gryllus campestris, diagrammatic from Sihler, 1924.)

Sensory hairs with intrahypodermal sense cells.—The structure
of a hair sense organ in which the sense cell lies within the normal
hypodermis may be illustrated by an example taken from the work
of Sihler (1924) on the sense organs of the cerci of a cricket (*Gryl-
lus campestris*).

The long hairs on the cerci of the cricket are set into deep cup-like
alveoli (fig. 12, *Alv*). The lips of each cup project above the surface
of the surrounding cuticula as a circular rim, while a horizontal
chitinous ring projects from the inner walls of the cup to brace the
base of the hair. The hair in these organs is rather solidly inserted
into the bottom of the cup and the usual articular membrane is lack-
ing. Beneath the hair is a large trichogenous cell (*HrCl*), with a
basal nucleus and its central part occupied by a vacuole (*Vac*) con-

tinuous with the hollow of the hair. Sihler does not distinguish in this organ a specific membrane cell, but, as just noted, the alveolar membrane is obliterated by the solid insertion of the hair. Several hypodermal cells, however, surround the trichogene and apparently contribute to the formation of the cup. At the side of the trichogene toward the base of the cercus is the large, oval, intrahypodermal, bipolar sense cell (SCl). Its distal process, Sihler says, penetrates the trichogenous cell and ends against the base of the hair. The proximal process (Nv) is continued into a sensory nerve trunk after following the basement membrane for some distance toward the base of the cercus. The sense cell and its distal process are invested in a nucleated continuation of the neurilemma of the nerve (Nlm).

The structure of the setal sense organ depicted in the above description is typical of that of all the hair-like sense organs of adult insects, (fig. 13 A, B) except that usually two cells are to be distinguished in addition to the sense cell, one of which is the trichogenous cell ($HrCl$ or ECl), and the other probably the hair membrane cell ($MbCl$ or CCl).

THE FUNDAMENTAL STRUCTURE OF AN INSECT SENSE ORGAN

A general survey of the structure of insect sense organs shows, in a large number of cases, that a single organ, or a single element of a compound organ, is formed of three cells or the multiples of three cells. We are, therefore, warranted in believing that the foundation structure of most types of insect sense organs consists of three hypodermal cells.

The structure of a simple three-cell sense organ, in which the cuticular part is of the hair type, is shown diagrammatically in figure 13 A. The most conspicuous element in the hypodermal part is the sense cell (SCl). Proximally the sense cell is continuous with the nerve (Nv), while distally it sends out a long, slender, terminal process (d) that goes to the cuticular part of the organ, in the case of a hair organ either attaching to the hair base or to the hair membrane, or penetrating the cavity of the hair. The body of the sense cell and at least the base of its distal process are invested in a thin, nucleated membrane continuous with the neurilemma of the nerve. Lying beside the sense cell, or distal to it, and usually surrounding its distal process, is a second cell, which, on account of its relation to the base of the seta, is clearly the trichogenous cell ($HrCl$), though in the adult organ its protoplasm is often retracted from the hair and from beneath the hair base, leaving here a vacuole (Vac) containing the

distal process (*d*) of the sense cell. The third cell (*MbCl*) is evidently the hair membrane cell, since its distal part embraces the end of the trichogene and terminates against the hair membrane, when the latter is present.

In many sense organs, the hair membrane cell and the trichogenous cell do not reach to the basement membrane, or the sense cell bulges into the body cavity and comes to lie proximal to the hair cell. The membrane cell, likewise, often lies distal to the body of the hair cell, and thus the three cells may come to be arranged serially along a radial axis, as shown at B of figure 13.
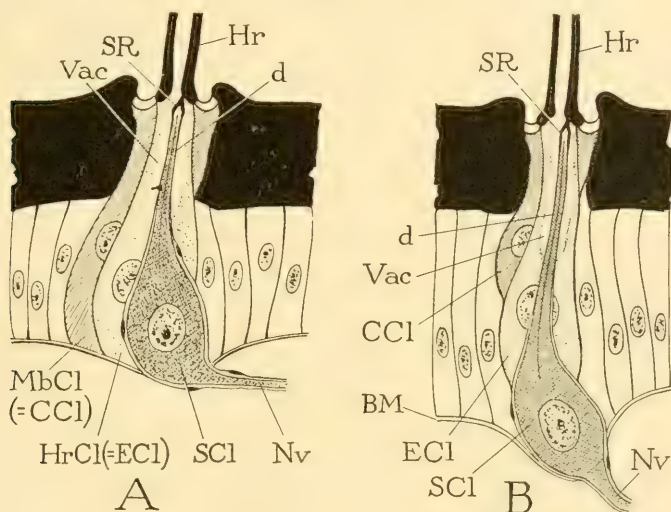
FIG. 13.—Diagrammatic structure of a hair sensillum.

A, showing the apparent origin of a sensillum from the hair membrane cell (*MbCl*), the trichogenous cell (*HrCl*), and a hypodermal sense cell (*SCl*). B, the three cells in axial arrangement, the membrane cell having become the cap cell (*CCl*) of a typical sensillum, and the trichogenous cell the enveloping cell (*ECl*).

A simple sensory complex, comprising the cuticular parts of the sense organ, the hypodermal elements, and the nerve, is known as a *sensillum*. The membrane cell of a sensillum is called the *distal enveloping cell,* or *cap cell* (fig. 13 B, *CCl*), and the trichogenous cell is distinguished as the *basal enveloping cell,* or simply the *enveloping cell* (*ECl*). In some sensilla the single sense cell is replaced by a group of sense cells (figs. 18, 24, *SCls*) ; and some sense organs are compound, each consisting of a group of simple sensilla.

The three cells of a sensillum appear to be partially telescoped one within the other, the neck of the sense cell being contained within the enveloping cell, and the distal part of the latter surrounded by the

cap cell. Horizontal sections through some adult sense organs show clearly that each enveloping cell completely encircles the one within it (fig. 24 B, C) ; but we must believe that this condition is a secondary one brought about by an overlapping of one cell about the other, since all may retain their connections with the cuticula. Berlese (1909) has shown that the cells of a sensillum are entirely separate at an early stage of their development.

CLASSIFICATION OF INSECT SENSE ORGANS

Since so little is known definitely concerning the functions of the various kinds of sense organs possessed by insects, except in the case of the tactile hairs and the eyes, we cannot at present speak of them as organs of smell, organs of taste, organs of hearing, etc. We must therefore, classify them according to their structure. Departing from the typical hair type, the external parts of the sense organs become peg-like or conical; losing the hair form altogether, they are reduced to papillæ or low domes, or they are flattened out to plates or membranes. In still others there is no external part except a pit, a disc, or a nodule of chitin to which the internal parts are attached. In the organs of vision the external parts are simple transparent corneæ or lens-like thickenings of the cuticula.

Most of the sense organs of insects can be grouped, therefore, according to the form of the external cuticular part, though with some the internal structure must be taken into account. Hence, following in part the well-known classification of Schenk (1903), the various kinds of sense organs known in insects will be described in this paper under the headings of *hair organs, campaniform organs, plate organs, chordotonal organs,* the *organ of Johnston,* and the *eyes.* The hair organs include those in which the cuticular part is typically setiform (*sensilla trichodea*), bristle-like (*sensilla chætica*), scale-like (*sensilla squamiforma*), or peg-like or cone-like (*sensilla basiconica*). The campaniform organs include the various sense papillæ, domes and " pores." The plate organs (*sensilla placodea*) are those in which the external part has the form of a thin membranous or chitinous disc or plate. The chordotonal organs and organ of Johnston are internal structures consisting of groups of simple sensilla attached to the cuticula of the body wall. The eyes are the various light-perceiving organs.

THE SENSE CELL

The essential element in an insect sense organ is the sense cell with its nerve connection. The truth of this is attested by the fact

that some invertebrate animals possess sense cells in the skin with no accessory structures. The common earthworm, for example, has specialized innervated cells in its hypodermis, which are regarded as being the receptive organs through which the creature receives a stimulus from light suddenly thrown upon its body. Insects are not known to have sense organs of so primitive a nature, though the photoreceptive tissue of eyeless Dipteran larvæ that respond to light has not been specifically determined. The chitinous parts of many
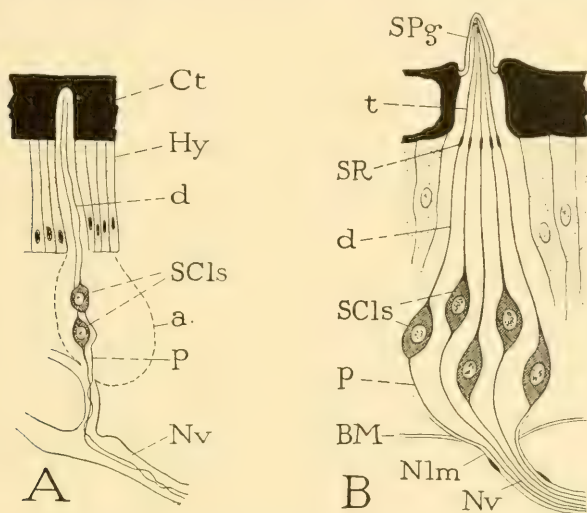
Fig. 14.—Showing the relation of the sense cells of a sensillum to the nerve and to the cuticular part of the sense organ.

A, two sense cells in an organ of the antenna of a wasp, stained by the Golgi method, each cell with a distal process (*d*) to the cuticular part of the organ, and a proximal process (*p*) continuous with a sensory nerve fiber (Vogel, 1923).

B, diagram of a sensillum containing a group of sense cells (*SCls*), the distal processes (*d*) ending in sense rods (*SR*) attached to cuticular part by terminal filaments (*t*), the proximal processes (*p*) continuous with nerve fibers.

insect sense organs, however, are reduced to mere points of the cuticula where the cellular elements are attached.

The sensory cells in the sense organs of adult insects are probably in all cases specialized hypodermal cells; that this is the usual case, at least, has been amply proven by the observations of many investigators on the development of diverse types of sense organs. Whether the sensory nerve fiber, however, is a product of the sense cell, or the axon of a nerve cell located elsewhere, may be regarded as still an open question, though the evidence, presented in the last section of this paper, appears to favor the second possibility, at least in the

case of the antennal sense organs of adult insects. Without conflict with either side of this question, it might be supposed that the primitive sensory apparatus of insects consisted of a specialized innervated hypodermal cell, as in the earthworms; but such a large number of the sense organs of insects suggest by their structure an origin from innervated hairs, that we must give serious consideration to the idea that the hollow cuticular seta was developed first, perhaps as a protective structure, and later became a sense organ through having the end of an innervated cell connected with its base. It, therefore, seems reasonable to suppose that the tactile hairs were the first specific sense organs to be acquired by insects, possibly excepting the eyes, and that from them were developed organs for perceiving chemical stimuli, sound stimuli, or whatever other stimuli are perceptible to insects. On any other basis, it is difficult to account for the uniformity of structure that runs through all types of insect sense organs except the eyes. The extent to which the hair structure can be traced in the various kinds of sense organs will be shown in the following sections of this paper.

The sense cell is, in most cases, easily distinguishable in the sensory complex by its large regular elliptical nucleus, which contains an abundance of chromatin, and by its oval or fusiform bipolar shape, drawn out at one end into the distal process, and continued at the other into a nerve. In many sense organs the sense cell is multiplied, there being from two to many cells (figs. 18, 24, *SCls*), the group sometimes being contained within the limits of the normal hypodermis, sometimes bulging or protruding from it into the body cavity; and sometimes the sense cells of neighboring sensilla form a continuous layer beneath the normal hypodermal cells (fig. 24). In all such cases, however, the sense cells are limited basally by the basement membrane of the body wall. Other sense organs consist of a bundle of sensilla in which there is an equal number of cap cells, enveloping cells, and sense cells.

The work of vom Rath (1896), Vogel (1923), and others appears to demonstrate that a nerve fiber extends into each sense cell from the connected sensory nerve trunk. Vogel says that in the antennal sensilla of wasps (*Polistes, Vespa*) an extremely fine fiber, less than half a micron in diameter, can be traced to the base of the sense cell in specimens stained by the Golgi method, and can be followed in the other direction into the nerve trunk of the organ, leaving thus no doubt of its being a nerve fiber. From the distal end of the sense cell, likewise a fiber somewhat thicker than the basal one can be traced outward to the cuticular part of the organ. Figure 14 A, taken from

Vogel, shows two stained cells of a sensory group with their proximal and distal processes clearly defined. The structure of a sense cell group might, therefore, be represented diagrammatically as at B of the same figure. The findings of those who have used differential staining methods do not substantiate the idea of Berlese (1909) that the nerve end invests the sense cell; but it appears likely that Berlese mistook for nerves the nucleated sheath which is continued over the sense cell and its distal process from the neurilemma of the nerve trunk.

THE RECEPTION OF SENSORY STIMULI

The question now arises whether the specific effect of the stimulus affecting a sense organ depends on the character of the external part, or on the nature of the sense cell itself. It is certain that the cuticular part of a sense organ must be adapted to receiving the specific stimulus to which the organ responds; the outer part of an eye, for example, must transmit light, and an auditory organ must receive sound waves. The receptive part of each sensillum must be so constructed that it will let in its particular class of stimuli and keep out all others. Chemical stimuli could not be supposed to penetrate a thick-walled structure, which, however, if loosely articulated, might respond to purely mechanical stimuli. On the other hand, an organ responsive to stimuli of taste and smell, a chemoreceptor, presupposes that the exposed part of the organ is somehow penetrable by odor or taste substances.

The earlier students of the sense organs of insects commonly assumed that those organs which they believed to be organs of smell and taste had perforations in their cuticular walls which allowed the substances to be perceived to come into direct contact with the ends of the sense cell processes. The presence of slits, pores, or openings of any kind in the outer covering of any insect sense organ, however, has been denied by all recent writers, except McIndoo (1914), and the major part of opinion now favors the idea that a chemoreceptive sense can be possessed only by those organs in which the cuticular walls are thin enough to be penetrated by substances of taste or smell or both.

That osmosis takes place readily through thin layers of the cuticula of insects has been demonstrated; and transudation must be assumed to take place in all glands derived from the ectoderm, the interior surfaces of which are covered by a delicate, imperforate cuticular intima. Eidmann (1922) has specifically shown that both acids and alkalies diffuse through the intestinal walls of the cockroach

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in from 10 to 15 minutes, though, with the thicker walls of the crop, the results of diffusion are not apparent until nearly 24 hours later. The cuticula of the crop is 5 to 8 microns in thickness, while that of the intestine is but 2 microns thick.

The cuticular walls of insect sense organs are in many cases extremely delicate, frequently not over half a micron in thickness, and in some cases so thin that sections of them do not show a double border under even the highest magnification. It is, therefore, not unreasonable to suppose that they are quickly permeable by substances in solution. Vogel (1923) has noted that the membranous cupola of a sensillum basiconicum of a wasp is colored by hematoxylin stain, and hence is permeable by it. We may believe, therefore, that sense organs in which the walls of the external part are at some point reduced to a thin membrane, half a micron or less in thickness, are organs capable of receiving chemical stimuli. If they are in fact chemoreceptors, then either they must be penetrated directly by odor or taste substances, or a liquid must exude from within them capable of absorbing such substances, thus providing the means of their transmission by osmosis to the ends of the sense cell processes.

The chief objection to the idea that a liquid exudes upon the surfaces of sense organs is the lack of any observations on the presence of such a liquid. Yet, the vacuole which surrounds the distal processes of the sense cells in many organs that have been regarded as chemoreceptive, suggests a possible source of a solvent liquid. Though Berlese's attempt to show that one of the elements of the insect sensillum is always a gland cell has not been generally accepted, it is not unreasonable to suppose that one of the cells might take on a secretive function in certain organs. The cell which contains the vacuole, when a vacuole is present (fig. 13 B, *Vac*), however, is the basal enveloping cell (*ECl*), which is the trichogenous cell (fig. 12, *HrCl*) and not a special gland cell.

What takes place within the sense organ when the latter is penetrated by the stimulating force or substance is entirely unknown, but it seems most probable that there must be produced some chemical change in the substance of the sense cell, which, in turn, acts upon the nerve and causes the latter to transmit a stimulus to the sensory center of the central nervous system. Perhaps every sense cell can be stimulated by a variety of stimuli, that which actually reaches it being normally determined by the nature of the external part of the organ; but the fact that in certain sense organs there is no specialized external part argues in favor of specificity even in the sense cells themselves.

THE SENSE RODS, OR SCOLOPALÆ

The sense cell of the sense organs of adult insects, being a transformed hypodermal cell, lies, during the formative stages, immediately beneath the cuticula. In the organs of vision the sense cells usually become separated from the cuticula during development either by invagination or by delamination; in the other organs the sense cells may retract inward, but they usually remain in connection with the cuticula by chitinous strands of varying length.

In the sensilla trichodea of the simpler types the distal process of the sense cell may remain attached directly to the inner surface of the cuticula of the hair membrane or the hair base (fig. 17 A, *d*). In most of the other sense organs of the hair, plate, campaniform, and chordotonal types, the end of the distal process of the sense cell is more or less withdrawn from the inner surface of the cuticula, but maintains its connection with the latter by means of a special cuticular structure known as the *sense rod,* or *scolopala* (the " Stift " or " Stiftkörperchen " of German writers).

The sense rod usually has the form of a hollow cone, peg, or fusiform rod attached by its apex to the inner surface of the cuticular part of the sense organ. The attachment to the latter may be either direct, or by means of a long filament drawn out from the apex of the rod.

The form and complexity of the sense rods vary much in different organs. In its simplest form, the rod is a mere cap, cone, or bulb *apparently* investing the end of the sense cell process. According to Hochreuther (1912) the sense rod in some of the tactile hairs of *Dytiscus* is a simple arrowhead-shaped peg, attached by its apex to the hair membrane or to the base of the hair. Sihler (1924) says there are two forms of sense rods in the sense organs of the cerci of *Gryllus campestris;* one form (fig. 15 A) has a pear-shaped head and a long cylindrical shaft, the other (B) ends in a club-shaped terminal enlargement. The walls of the rods of each form have ten longitudinal thickenings or ribs (*r, r*), which, however, are not continuous and their separated parts form two or three ribbed zones in the walls of the rods, the positions varying in different organs (A, B, *r, r*). The head of each rod contains a dark-staining *apical body* (*AB*) from which there is continued a fine *axial fiber* (*AxF*) into the body of the sense cell. In the campaniform organs of *Dytiscus marginalis,* Hochreuther (1912) describes a simple club-shaped rod (fig. 15 C) with an apical point inserted into the dome-like external part of the organ (*Do*). There is here no apical body within the rod and the axial fiber (*AxF*) is continuous to its tip. In the

campaniform organs on the halteres of Diptera, according to Pflug-staedt (1912), there is a similar sense rod (fig. 15 D, *SR*) attached by a chitinous plate to the under surface of the dome (*Do*). The rod in these organs contains an elongate apical body (*AB*), which is evidently the same structure as that termed the " manubrium " by
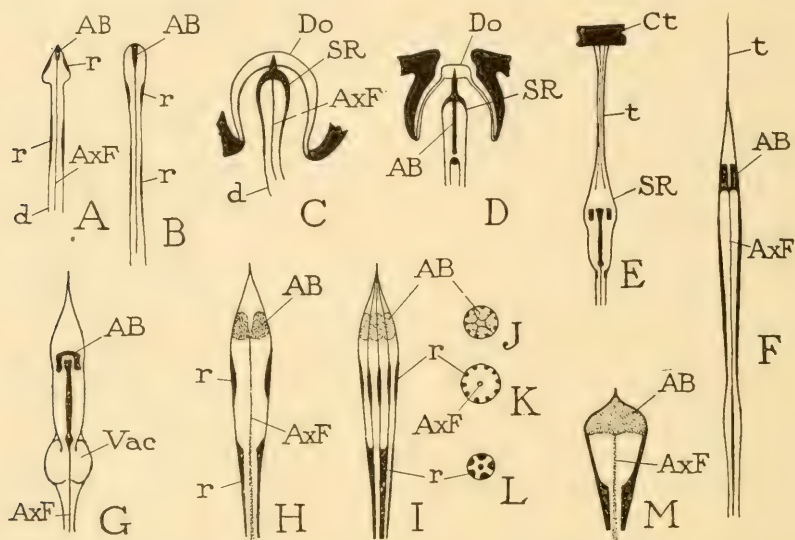
FIG. 15.—Various forms of sense rods, or scolopalæ, in different kinds of sense organs.

A, B, sense rods of tactile hairs of cerci of *Gryllus campestris* (Sihler, 1924). C, sense dome and rod of campaniform organ of *Dytiscus marginalus* (Hochreuther, 1912). D, dorsal scapel campaniform organ and sense rod of halter of *Syrphus* (Pflugstaedt, 1912). E, scolopala of halter of a fly (Pflugstaedt). F, scolopala from chordotonal organ of wing base of a Lepidopteran, *Cheimatobia* (Vogel, 1912). G, scolopala of chordotonal organ of halter of *Syrphus* (Pflugstaedt). H, optical longitudinal section of scolopala of tympanal chordotonal organ of *Acridium ægypticum* (Schwabe, 1906). I, same as H, surface view. J, cross-section through apical body (*AB*). K, cross-section through middle of scolopala. L, cross-section through basal part of scolopala. M, optical longitudinal section of scolopala of chordotonal crest in leg of *Decticus verrucivorus* (Schwabe, 1906).

Janet (1904) in the campaniform organs of ants. Vogel (1911) describes sense rods in the campaniform organs of the wing bases in Lepidoptera, which apparently closely resemble those of the sense organs of the cerci in Orthoptera. Each rod, he says, has a pear-shaped head containing a dark-staining apical body to which is attached the end of an axial fiber from the sense cell, and the rod walls have about ten internal rib-like thickenings.

The sense rods of the chordotonal organs have been carefully studied in many different insects. They are often specifically called *scolopalæ,* but there is no reason for distinguishing scolopalæ from sense rods in general, or for limiting the term to the chordotonal rods. The scolopalæ of one of the chordotonal organs in the base of the halter of Diptera are described by Pflugstaedt (1912) as attached to the cuticula, each by a long terminal fiber (fig. 15 E, *t*) formed by a continuation of the ribs of the scolopala walls. Vogel (1912) finds each rod in the chordotonal organs of the wing bases in Lepidoptera likewise attached to the cuticula by a long terminal filament (fig. 15 F, *t*). In some chordotonal organs there is a vacuole in the sense cell process at the base of the scolopala (fig. 15 G, *Vac*), which is traversed by the axial fiber (*AxF*). This vacuole should not be confused with the vacuole of the basal enveloping cell, which contains the distal process of the sense cell.

The structure of the sense rods in the tympanal chordotonal organs of Orthoptera has been particularly studied by Schwabe (1906). Each scolopala of the sensory body attached to the inner surface of a grasshopper's " ear " (fig. 27 B, *SB*) is a minute hollow rod, about 23 microns in length, fusiform, pointed at the distal end, slightly tapering proximally (fig. 15 H, I). Stained specimens, examined under high magnification, show that the walls of the rod are marked by longitudinal ribs (*r*) formed by thickenings on the inner surface (J, K, L). On the distal two-thirds of the scolopala there are ten ribs, each enlarged at its middle; but proximally the ribs unite in pairs, forming five thicker ridges on the basal third of the rod. The head of the scolopala is occupied by a dark-staining apical body (H, I, J, *AB*) to which is attached the end of the axial fiber (H, *AxF*) from the sense cell. In the rods of the chordotonal organs of Cerambycid larvæ, Hess (1917) finds seven ribs on the basal part that fork to form 14 on the distal part. Vogel (1923 *a*) says that the ribs of the chordotonal rods of the cicada appear to be on the external surfaces of the rods.

In the chordotonal organs, the sense rods are usually some distance removed from the cuticula, being situated in the outer end of the enveloping cell or partially in the base of the elongate cap cell (fig. 26, *SR*). They are usually connected with the cuticula, as we have seen (fig. 15 E, F), by a long terminal filament (*t*) traversing the cap cell, but in some cases the connection appears to be lost. Thus, as noted by Schwabe (1906) in the tympanal organs of the Orthoptera, and by Hess (1917) in the chordotonal organs of Cerambycid larvæ, the terminal fiber, if present, is continued from

the apex of the rod only a fourth or a third of the length of the cap cell. Usually, in the tympanal organs of the Orthoptera, according to Schwabe, there is no terminal filament.

In the sensilla of the sensory pegs, cones, plates, and some of the smaller thin-walled hairs, in each of which there is a group of sense cells (figs. 18, 24, *SCls*) with their terminal processes bound together in a bundle or fasciculus (*Fas*), the minute sense rods (*SRs*) are also removed a considerable distance from the cuticula. They are attached to the latter by a long terminal strand (*TS*) composed apparently of the individual terminal filaments (fig. 14 B, *t*) of the sense rods (*SR*).

From a review of the descriptions of the sense rods in the various insect sense organs given by recent investigators, we may conclude that all the rod-like structures are homologous organs. Most investigators believe that the rods are differentiations of the ends of the sense cell processes, and this idea appears to be substantiated by all the known facts bearing on their nature. The appearance and staining properties of the rods suggest that they are weakly chitinous. Vogel says that the scolopalæ of the chordotonal organs in the wing bases of Lepidoptera have the same optical qualities as other thin chitin, and that the inner walls and the ribs stain in eosin and hematoxylin, just as does the inner part of the chitin of hairs and of the body wall. The recent observation by Sihler (1924), however, that the sense rods in immature Orthopteran insects *are shed during a molt* is a most important addition to our knowledge of these heretofore puzzling structures, and, if correct, fixes their status by showing conclusively that they are not only of a cuticular nature, but that they belong to the cuticula of the body wall. Sihler bases his claim of the molting of the sense rods on observations on the sense rods of the tactile hairs of the cerci of an Acridian, *Gomphocerus rufus*. He says that when the exuviæ are separated from the cuticula during a molt, there is usually to be seen attached to the base of each hair of the exuviæ a tubular appendage in which are distinguishable both the head and the ribs of the sense rod as observed in specimens prior to molting (fig. 15, A, B).

If, then, we are to regard the sense rod, or scolopala, as a chitinous product of the end of the sense cell, we must next consider how it may be formed. Sihler and most other recent writers regard the rod as a cuticular sheath (fig. 16 A, *SR*) covering the end of the distal process (*d*) of the sense cell, and attached by its apex either directly, or by means of a terminal stalk or filament, to the cuticula of the body wall. However, from a study of other internal chitinous

structures, we are not warranted in assuming that a cuticular process ever grows inward except as an ingrowth from the exterior surrounded by a hypodermal matrix. A muscle " tendon " serves as a good example of a structure produced in this way. As shown by Janet (1907), the long tendon-like stalk to which some insect muscles are attached is produced from a single hypodermal cell. The tendon . cell (fig. 16 C, *TndCl*) elongates and its interior secretes a chitinous continuation (*Tnd*) from the outlying cuticula (*Ct*), which finally (B) occupies the entire length of the mature tendon cell and forms at its inner end a funnel-shaped cup holding the end of the muscle
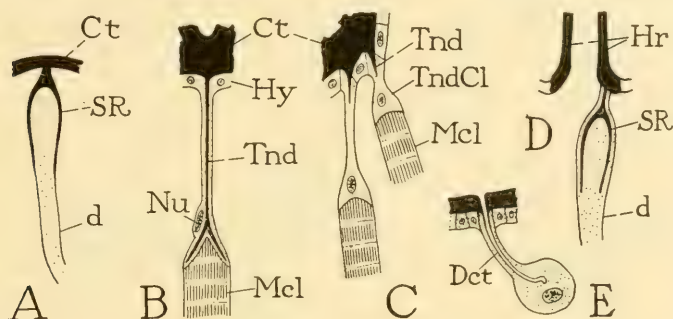
Fig. 16.—Theoretical suggestions of the morphology of the sense rod.

A, sense rod (*SR*) of a campaniform organ of *Dytiscus*, as illustrated by Hochreuther (1912), attached to cuticular part of organ (*Ct*) and ensheathing the end of distal process (*d*) of a sense cell. B, structure of a muscle tendon as illustrated by Janet (1907), the tendon (*Tnd*) is an *intracellular* product continuous with the cuticula (*Ct*). C, early stages in formation of muscle tendons (Janet). D, theoretical relation of a sense rod (*SR*) to distal process (*d*) of a sense cell suggested by comparison with a muscle tendon (B). E, a one-celled gland with intracellular duct.

(*Mcl*). The tendon is probably to be regarded, theoretically, as a hollow ingrowth of the cuticula, corresponding structurally with the duct of a one-celled gland (fig. 16 E, *Dct*). The important feature to be noted in both these structures, however, is that the hypodermal matrix *surrounds* the cuticular ingrowth.

Applying this principle of the known method of growth of internal cuticular organs to the sense rods, we must suspect that each rod is formed within the distal end of the sense cell process, as shown diagrammatically at D of figure 16, rather than on the outer surface of the process. If produced in the second manner, the rod could not be renewed after a molt and reëstablish its connection with the outer cuticula, especially where the end of the sense cell is retracted from the latter. The parts in question are so minute that the actual facts

of construction cannot often be observed. Schwabe (1906) is the only writer who has said definitely that the sense rods lie within the distal part of the sense cell process, though Erhardt (1916) gives figures of the chordotonal organs from the wing base of *Eristalis floreus* in which the scolopalæ are shown distinctly inside the long distal processes of the sense cells.

Eggers (1923) would explain the scolopalæ of the chordotonal organs and of the organ of Johnston as originating from a fibrous differentiation of the terminal part of the sense cell process, a condition which he finds in the sense cells of the primitive organ of Johnston in the antenna of a dragonfly larva. The distal parts of the fibers, Eggers suggests, come together to form the terminal filament of the scolopala, while their proximal parts fuse to form the ribbed walls of the scolopala itself. This explanation, however, leaves us to assume that the fibers are chitinizations of the lateral walls of the sense cell, and, therefore, meets with the same objection above noted, viz., that it violates the rule of similar internal chitinizations being formed otherwise than as a surface deposit, or as a prolongation of the surface deposit within the body of a cell.

THE AXIAL FIBER

An axial fiber (fig. 15 A, C, F, H, and fig. 26, *AxF*) has been observed in all the different groups of insect sense organs, though it has not been shown to exist in every organ. When present, it traverses the distal process of the sense cell from the body of the cell to the sense rod (fig. 26). Its distal end terminates in the apical body (fig. 15 H, *AB*), when the latter is present, or continues to the end of the rod (C) when an apical body is lacking. Proximally, the fiber is usually lost in the body of the sense cell, but Hess (1917) says, in the chordotonal organs of Cerambycid larvæ, it can be traced through the sense cell into the nerve, and Schwabe (1906) claims that it separates within the sense cell into fine fibrils which unite again into a single fiber entering the nerve.

The nature of the axial fiber has not been determined. Some investigators believe that it is the end of the true nerve fiber of the sensillum; others claim that it is of a chitinous texture, though Sihler observes that it is not cast off with the molted rod during ecdysis.

IV. THE HAIR ORGANS

All sense organs in which the cuticular part has the structure of a hair, whether setiform, bristle-like, club-shaped, scale-shaped, cone-

shaped, or peg-like, and whether exposed on the surface or sunken into a pit or deeper cavity of the cuticula, may be grouped together as the hair sense organs, since the cuticular part in each is clearly a modified seta. Under this heading we can distinguish *sensilla trichodea* (sense setæ), *sensilla chætica* (sense bristles), *sensilla squamiforma* (sense scales), *sensilla basiconica* (sense cones and pegs), *sensilla cœloconica* (sense pits), *sensilla ampullacea* (sense flasks).
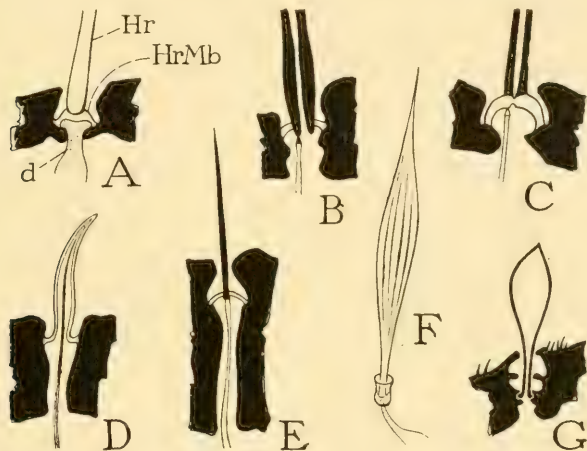
FIG. 17.—Sensory hairs of various forms, and a sensory scale.

A, hair sense organ with distal process of sense cell (*d*) attached directly to articular membrane (adapted from Hochreuther, 1912, sensory hair of *Dytiscus*). B, distal process attached by sense rod to base of hair in sense organ of labium of *Dytiscus* (Hochreuther). C, sense hair with imperforate articular membrane on mandible of *Dytiscus* (Hochreuther). D, thin-walled sensory hair with terminal strand of sense cell processes attached in tip. E, a solid sensory spine on pharyngeal plate of *Dytiscus* (Hochreuther). F, a sensory scale of wing of *Notris verbascella* (Freiling, 1909). G, club-shaped sensory hair of cercus of *Gryllotalpa vulgaris* (Sihler, 1924).

SENSILLA TRICHODEA

The sensitized hair is clearly the most primitive of insect sense organs, excepting possibly those eyes of certain Dipteran larvæ that consist of little else than sensitive hypodermal cells. A sensory hair of the trichodea variety is typically setiform, but there is much variation in length and especially in the thickness and density of the hair walls. The longer, stiffer sensory hairs are probably all organs of touch; they are known as *tactile hairs*. Short hairs with thin transparent walls are usually regarded as organs for receiving stimuli of smell and taste; they are distinguished as *chemoreceptive* hairs.

Tactile hairs are common in all the major groups of the Arthropoda; in insects they occur on most parts of the body and appendages,

and in the anterior region of the alimentary canal. The movement of
the hair may be supposed to register a more gentle tactile stimulus
than would the effect of pressure on the general body surface, es-
pecially where the latter is covered by a coating of dense chitin. By
means of the sensitive hairs, moreover, the insect can become aware
of the approach or nearness of an external object before coming into
actual contact with it.

The sensillum of a tactile hair contains usually but one sense cell
(fig. 13 B, SCl), though some are described and figured as having
two or several sense cells. The distal process of the sense cell is at-
. tached to the hair membrane or to the base of the hair itself, or per-
haps within the cavity of the hair. The attachment may be direct (fig.
17 A), but it is usually by means of a terminal sense rod (B). Some
tactile hairs appear to be closed at the base by an imperforate mem-
brane (C).

The supposedly chemoreceptive hairs are short and weakly chiti-
nized, having thin, transparent walls. Each is innervated through a
group of sense cells, the terminal strand from which penetrates the
cavity of the hair to its tip (fig. 17 D). The sensillum of a chemo-
receptive hair, therefore, is identical with that of a chemoreceptive peg
(fig. 18) except for the length and shape of the cuticular part. Chemo-
receptive hairs are found particularly on the antennæ and the mouth
parts.

SENSILLA CHÆTICA

The sense organs classed under this head are separated from the
tactile hairs of the trichodea type only by the more spine-like or
bristle-like character of the external parts, but the distinction is arti-
ficial and unnecessary since the setal organs vary in shape from slender
hairs to thick clubs (fig. 17 G). The sensory spines and bristles are
usually thick-walled and densely chitinous; some are said to be solid
structures (fig. 17 E). Probably most of them are organs of touch.

The organs along the sides of the abdomen in the Nepidæ, consist-
ing of small cavities with a fringe of movable, innervated spines within
the respiratory chambers of the young, and of plates associated with
the abdominal spiracles covered with a mat of recumbent spines in
the adult, probably offer an example of a special use of a tactile spine.
These organs have been elaborately described by Baunacke (1912),
who believes that they are static in function. Their spines lie hori-
zontally in the plane separating the air in the air space beneath them
from surrounding water, and Baunacke, pointing out that a tilting
of the body in any direction would alter the plane of the spines,

argues that this motion would register the position of the insect in the water.

Since scales are but modified hairs, it is not surprising to find that some of them should be innervated in the same manner as the tactile hairs. Sense scales have been described on the wings of Lepidoptera by Guenther (1901), Freiling (1909), and Vogel (1911). Vogel says that innervated scales are found on the wings of all Lepidoptera, even in primitive forms like *Hepialis*. They occur on both sides of the wings, mostly on the veins, and especially on the marginal veins, but they may be present also on the basal parts of the wings wherever there is an internal space sufficiently large to allow a nerve to penetrate.

The sense scales are elongate fusiform in shape, with fewer ribs than the other scales, and each has the distal part drawn out into a long, tapering point (fig. 17 F). The spaces between the internal ridges of a sense scale, Freiling says, are so reduced that the scale is almost a solid structure. Each sensory scale is innervated through a single large sense cell, the distal process of which, according to Vogel, ends in a cone-shaped sense rod attached to the base of the scale. The sense scales are evidently tactile in function.

SENSILLA BASICONICA

Sensory pegs and cones are undoubtedly to be regarded as hairs reduced in size, and there is no sharply dividing line between sensilla trichodea and sensilla basiconica. The character of the external parts and the structure of the internal parts of the peg sensilla, likewise separate these organs into two groups, there being thick-walled or even solid pegs innervated each through a single sense cell, and thin-walled pegs innervated each through a group of sense cells. The former are regarded as receptive to mechanical stimuli, the latter to chemical influences.

Sense pegs and cones have been described on all parts of the body and appendages of various insects, on the epipharynx and hypopharynx, and in the pharyngeal cavity. Many of them are clearly but short hairs of the tactile kind, but the typical pegs, occuring particularly on the antennæ and the mouth parts, are of the chemoreceptive variety. In these the walls of the peg or cone are thin and transparent (fig. 18, *Pg*), some terminating in a membranous cap. The sensillum comprises a large cap cell (*CCl*), a vacuolated enveloping cell (*ECl*), and a compact group of sense cells (*SCls*). The

distal processes from the latter form a cylindrical bundle (*Fas*) traversing the vacuole (*Vac*) of the enveloping cell, and attached by a terminal strand (*TS*) in the apex of the peg. In the Hymenoptera, at least, the terminal strand consists apparently of the terminal fibers of the minute sense rods (*SRs*), which latter are here far removed from the external surface.
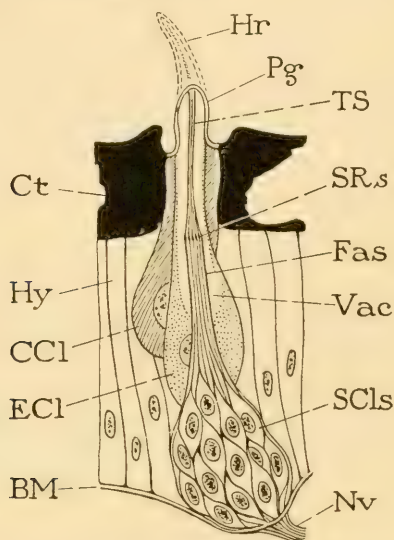
FIG. 18.—Diagrammatic structure of the sensillum of a thin-walled peg (*Pg*) or hair (*Hr*) supposed to be receptive to chemical stimuli.

The distal processes of the sense cells (*SCls*) form a compact fasciculus (*Fas*) ending in a terminal strand (*TS*) of cuticular fibers from the sense rods (*SRs*), attached within tip of external cuticular part; enveloping cell (*ECl*) with vacuole (*Vac*) containing fasciculus and terminal strand.

SENSILLA CŒLOCONICA

Sense organs of this type are simply sensory pegs sunken into shallow cavities of the cuticula (fig. 19 A, B), and again, as with the hairs and exposed pegs, some are thick-walled or solid and innervated each through a single sense cell, while others are thin-walled and innervated each through a group of sense cells. It becomes evident, that a truer classification of both hair and peg sense organs, and one probably more coincident with their function, might be based on the internal structure of the sensillum rather than on the form of the external part, if the state of our knowledge would permit.

Besides the simple pit organs, each with a single peg, there are pits containing each a number of pegs. Organs of this kind occur

on the antennæ of some Diptera; those of the housefly are described
by Röhler (1906). Some of the cavities contain a single group of
from 10 to 20 pegs; others are compound, the cavities being divided
into shallow compartments, each with its group of pegs. These or-
gans were called " otocysts " by Graber, but Röhler regards them as
olfactory in function. The labial palpus of the cabbage butterfly
(*Pieris*) also has at the tip a deep cavity containing many sense pegs.

SENSILLA AMPULLACEA

This term is given to sense organs of the sunken peg type in which
the cuticular cavity is deeper and more flask-like (fig. 19 C) than
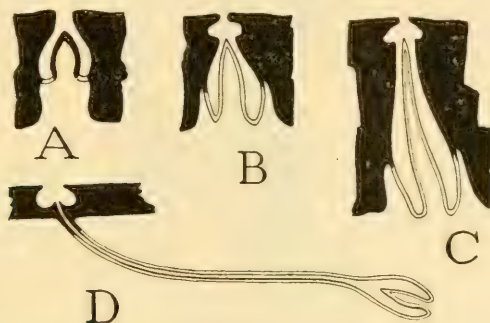
Fig. 19.—The cuticular parts of several varieties of sensilla cœloco-
nica (A, B) and ampullacea (C, D).

A, simple pit peg with thick chitinous walls. B, thin-walled peg more
deeply sunken into cuticular cavity. C, a flask-shaped organ. D, a
Forel's flask with long tubular neck.

in the typical sensilla cœloconica. In some, the "flask" is far re-
moved from the surface and is connected with the outer cuticula
by a long, tubular neck (D). Organs of this kind are known as
Forel's flasks. Sensilla ampullacea are particularly characteristic of
the antennæ of Hymenoptera. They are usually regarded as organs
of smell.

V. THE CAMPANIFORM ORGANS

The sense organs grouped in this class are clearly related to one
another structurally. They are all, however, of such simple form
and yet vary so much in shape, that they present no feature on which
a descriptive or a distinctive name can be based. They have been
called *vesicles, organs of Hicks, papillæ, cupola organs, dome organs,
umbrella organs, bell organs,* and *sense " pores."* Since the external
part commonly has the shape of a thin-walled dome or bell, or sug-
gests that it has been derived from such a form, the name *campani-*

form organs, as used in a general sense by Berlese (1909), is here selected for euphony and because in descriptive value it is equal to any of the others.

The external parts of the campaniform organs are, in most cases, small, rounded, dome-like papillæ or but slightly convex swellings, usually less than 25 microns in diameter; but sometimes they are reduced to minute discs, slightly sunken in the outer surface of the body wall, having the appearance of hair follicles from which the
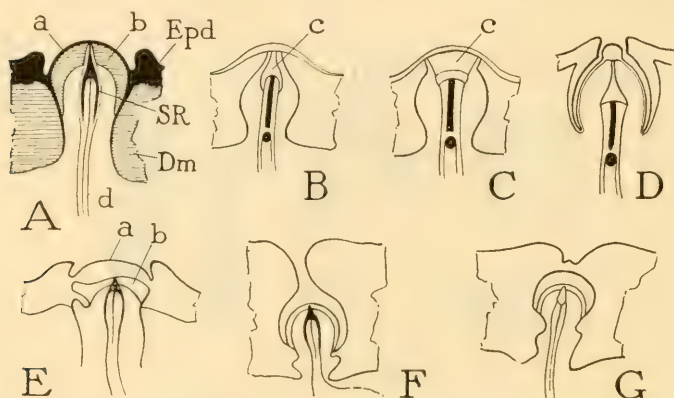
Fig. 20.—Various types of campaniform organs, vertical sections through cuticular parts and ends of sense cell processes with sense rods.

A, Diagrammatic structure of a typical organ: *a,* outer lamella of dome; *b,* inner lamella, the cone or cushion; *d,* distal process of sense cell with axial fiber ending in the sense rod (*SR*).

B, organ from base of halter of *Calliphora* (Pflugstaedt, 1912): *c,* attachment plate of sense cell process. C, longitudinal section of same. D, dorsal scapal organ of halter of *Syrphus* (Pflugstaedt). E, from cercus of *Periplaneta americana* (Sihler, 1924). F, sunken organ on labium of *Dytiscus* (Hochreuther, 1912). G, sunken organ with no apparent external opening, on mandible of *Dytiscus* (Hochreuther).

hairs have been removed, though they are usually distinguishable from the circular hair sockets by a more elliptical or oval form.

The dome or disc in typical examples usually consists of a thin, outer, imperforate lamella of dense chitin (fig. 20 A, *a*), and of an inner layer of clear softer chitin (*b*). These two parts probably belong to the epidermal and dermal layers, respectively, of the body wall cuticula (*Epd* and *Dm*). In stained specimens the appearance is sometimes reversed because the softer inner layer, according to most writers, colors more darkly in ordinary staining reagents. The inner layer is the *cushion* (*Polstermasse*) of German writers, the *cone* of McIndoo (1914). Usually it has the form of a cone or an inverted cup or saucer beneath the outer lamella. In many campani-

form organs the cone is not present, or at least has not been distinguished by those who have described and figured the organs. When present, it is perforated by a central opening or by an axial slit, through which the distal end of the sense cell process (d) is inserted on the under surface of the outer lamella. Beneath the cone is the usual canal in the cuticula, which does not differ from that of the sensory hairs.

The innervation of the campaniform organs is always through a single sense cell (fig. 21, SCl). The sense cell is usually large, oval
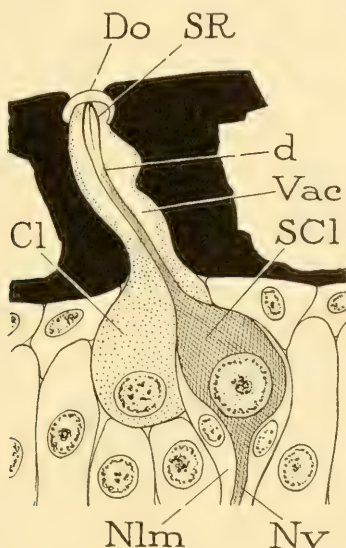
Fig. 21.—Structure of a campaniform sensillum (diagrammatic from Sihler, 1924, organ on cercus of *Periplaneta orientalis*).

Cuticular canal beneath dome occupied by a single cell (Cl), apparently the trichogenous cell (fig. 13 B, ECl); no cap cell (membrane cell) shown in this organ.

or fusiform; it lies within the hypodermis but may project below the general level of the basement membrane. In some organs the distal process (d) appears to end directly on the inner surface of the outer lamella of the dome, but in most of them there is a typical sense rod (SR) at the end of the process.

The other cells of the campaniform sensillum have not been definitely identified with those of the hair-bearing sensilla. Erhardt (1916) notes the presence of enveloping cells associated with the sense cell in the campaniform organs of the wing basis of *Chrysopa*. Vogel (1911) finds two enveloping cells in the organs of the wing bases of Lepidoptera, but he says their boundaries are not distinct.

Pflugstaedt (1912) describes and figures a large cell beneath the dome of each organ on the halteres of Diptera; and Sihler (1924) says that the sense cell of the cercal campaniform organs of Orthoptera is always accompanied by a dome-forming cell. The " dome cell " (fig. 21, Cl) in its relation to the dome (Do) of a campaniform organ corresponds closely with the cap cell of a sensillum placodeum (fig. 24 A, CCl) in its relation to the plate (Pl); but the two sets of organs are only superficially similar, and the campaniform dome cell, as figured by Sihler in the cockroach (fig. 21, Cl), suggests the enveloping, or trichogenous, cell of a hair sensillum (fig. 13 B, ECl). The single large cell in the sense organs of the rectum of Lamellicorn beetle larvæ (fig. 22, Cl), which appear to be organs of the campaniform type, is described by Orlov (1924) as a gland cell. The question, therefore, as to whether the dome of a campaniform organ represents the reduced hair or the hair membrane of a sensillum trichodeum must be regarded, for the present, as an unsettled one.

It is to be noted that the campaniform organs, having each a single sense cell, fall structurally in the class of the tactile organs of the hair and peg varieties.

The campaniform organs are known to occur on the head, thorax, abdomen, the antennæ, mouth parts, legs, wing bases, cerci and sting of various adult insects in all the principal orders, and they have been found on the larvæ of some species. Their external structure was first described by Hicks (1857, 1859) who called them simply " vesicles." Since then, both the external and the internal structure of the organs, described under various names, have been more closely studied by many other investigators. The distribution of the organs over the various parts of the body and appendages of insects in all the principal orders has been described extensively by McIndoo (1914-1920). The structure of the organs of the wing bases has been particularly studied by Guenther (1901), Freiling (1909), and Erhardt (1916); those of the halteres of Diptera, by Hicks (1857, 1859), Weinland (1891), Pflugstaedt (1912), and McIndoo (1918). Hochreuther (1912) describes the organs on the head, antennæ, mouth parts, and legs of *Dytiscus marginalis,* and Lehr (1914) those on the wing bases of the same species. Sihler (1924) gives an account of the campaniform organs on the cerci of Orthoptera. Janet (1904) describes the organs of ants, and McIndoo (1914) and Trojan (1922) record their presence on the sting of the honeybee.

The shape of the campaniform dome varies in different organs. It may be strongly convex and evenly rounded (fig. 20 A), or its

midline may be elevated to form an axial ridge (D) ; it may again be more or less flattened (B, C, E), or reduced to a minute disc. Its walls may be thick and densely chitinous, membranous, or so thin as to be scarcely perceptible. The dome is sometimes freely exposed on the surface of the body cuticula, but it is often protected by chitinous outgrowths about it (A, E), or by being itself sunken into the cuticula (D, F, G). In the sunken type, the cavity containing the dome may open directly on the surface (D), or by means of a tubular canal (F), while sometimes it appears to be entirely closed (G). In the last case, however, as admitted by both Janet (1904) and Hochreuther (1912), a pore to the exterior might be present, though escaping detection in sections.

The simplest of the campaniform organs are those in which the external part is reduced to a minute circular oval disc, which may be situated at the surface of the body cuticula or sunken into a pit. Those located at the surface or in shallow depressions of the body wall are common on the wing bases, legs, and other parts of many insects. They have been described particularly by McIndoo under the name of " olfactory organs " or " olfactory pores." Simple organs of the sunken variety are described by Erhardt (1916) on the wing bases of dragonflies, each consisting of a delicate, imperforate membrane spanning the floor of a cuticular pit. The cuticular canal beneath the membrane contains the end process of a sense cell and the distal part of an enveloping cell.

Finally, there should be mentioned here the organs found by Orlov (1924) in the posterior part of the alimentary canal of the Lamellicorn larva, *Oryctes,* since these organs apparently belong to the campaniform group. Each consists, according to Orlov, of a delicate, circular chitinous membrane (fig. 22, *a*) which may be slightly convex or concave. Beneath the membrane is a large cell (*Cl*), which Orlov regards as a gland cell, and, beside this, a bipolar sense cell (*SCl*), the distal process of which goes to the center of the membrane. These organs, Orlov says, are similar in structure to sense organs distributed over the body in *Melolontha* larvæ. Other beetle larvæ possess campaniform organs of the more usual type. McIndoo (1918 *a*) describes simple campaniform organs ("olfactory pores ") distributed over the head, antennæ, mouth parts, thorax, and legs of the larva of *Allorhina* (Scarabæidæ), and compound organs on the terminal segments of the antennæ. The compound organs consist of groups of several hundred simple organs situated in thin oval areas, or plates, of the antennal walls.

The function of the campaniform organs is still a subject of speculation. Some writers have suggested that the organs respond to vi-

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bratory stimuli, or that they register air pressure. Experiments made by McIndoo (1914) and others appear to indicate that insects are responsive, in a certain degree, to odors by organs other than those of the antennæ, and it is most reasonable to suppose that these organs are the widely spread campaniform organs. McIndoo's claim, however, that the outer membrane of the small disc-like organs is perforated, and allows the distal end of the sense cell process to come into direct contact with the air, has not been verified. All other recent students of the campaniform organs, including Freiling, Vogel, Pflugstaedt, Erhardt, Sihler, state that the outer membrane or the outer lamella of the dome is never traversed by a pore or other opening. The closing membrane, though, may be very thin; Vogel says that the outer lamella of the organs of the wing bases of Lepidoptera
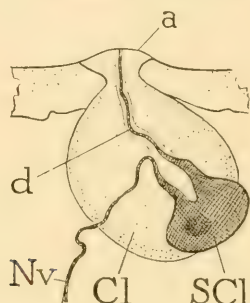
FIG. 22.—A rectal sense organ of larva of *Oryctes* (Orlov, 1924), apparently a simple organ of campaniform type.

a, outer membranous disc; *Cl,* cell beneath disc; *d,* distal process of sense cell (*SCl*) ; *Nv,* nerve fiber.

is only from 8/10 to 1 micron in thickness. Such organs might be chemoreceptors ; but, as already noted, chemoreceptive organs in general are innervated through a group of sense cells, while all campaniform organs have a single sense cell, a feature characteristic of sense organs responding to mechanical stimuli. The outer part of many of the campaniform organs, on the other hand, is so thick as to preclude any idea of a chemical sense in connection with them.

VI. THE PLATE ORGANS

The sense organs known as the sensilla placodea, in their typical form, consist of thin chitinous plates, elongate, elliptical, or oval in outline, set over large cavities or pores in the cuticula. They were, therefore, designated "pore plates" by Leydig (1860) and they have since commonly been known by this rather ambiguous name.

The plates of the sensilla placodea often resemble the domes of the sensilla campaniforma (Cf. figs. 23 B, I and 20 E, D), and the plate organs might be supposed to represent an evolutionary stage beyond the campaniform organs in which the dome has been finally flattened to a chitinous plate. A comparison of the internal structure of the two sets of organs (figs. 21 and 24), however, shows that they belong to different series. In each sensillum placodeum there is a group of sense cells (fig. 24, *SCls*), and also a cap cell (*CCl*) and
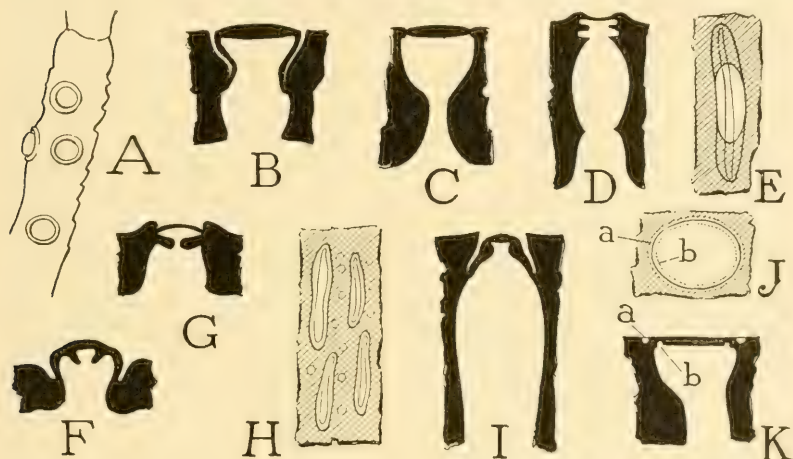
Fig. 23.—Cuticular parts of sensilla placodea in surface view and in section.

A, discs near end of third segment of antenna of grain aphis. B, section of plate on antenna of *Dytiscus* (Hochreuther, 1912). C, same from *Cetonia aurata* (vom Rath, 1888). D, same from *Necrophorus vespillo* (Ruland, 1888). E, surface view of antennal plate of *Ophion luteus* (Ruland). F, section of antennal plate of *Cynips gallæ tinctoriæ* (Ruland). G, section of antennal plate of *Ophion luteus* (Ruland). H, surface view of antennal plates of *Vespa crabro* (Ruland). I, transverse section of one of same. J, surface view of antennal plate of *Apis mellifera*. K, longitudinal section of same: *a*, outer ring of light chitin; *b*, inner groove.

enveloping cell (*ECl*) of typical form and relation to each other and to the sense cells. The external plate (*Pl*), moreover, lies over the cap cell, or hair membrane cell, and is, therefore, evidently the chitinized hair membrane rather than the base of the hair. The plate organs, hence, belong structurally to the chemoreceptive series, while the campaniform organs belong to the tactile series. The campaniform dome is probably the reduced hair; the plate appears to be the chitinized hair membrane. These statements are, of course, tentative and must be tested by a further study of the histology of the organs in question.

Plate-like sense organs occur on the antennæ of aphids, Coleoptera, and Hymenoptera, and have been described on the mandibles and the maxillary palpi of *Dytiscus*. They have not been studied with equal care in each of these three groups of insects, and it is possible they are not all homologous structures.

The organs on the antennæ of aphids consist externally of elliptical, oval, or sometimes elongate membranous discs (fig. 23 A). Those present on the insect at hatching are said to persist through all the molts to the mature insect, including both asexual and sexual forms; others appear at the last molt, especially on the winged forms, and are organs of the mature insect only. The internal structure of the organs in the aphids has been but little studied. Flögel (1905) gives a crude figure of a section through one of the discs of *Aphis ribis,* beneath which he shows a mass of sense cells with their distal processes spread over the entire under surface of the membrane. Externally, he says, the membrane is surrounded by a groove, which in turn is encircled by a chitinous ridge. The membrane itself is from 1 to 1-1/2 microns in thickness, the surrounding chitin being 7 microns thick, from which Flögel argues that the membrane is capable of being traversed by a liquid that could absorb odor substances. He believes, therefore, that the antennal organs in aphids have an olfactory function. Organs of a similar external appearance occur also on the legs and wing bases of aphids (Baker, 1917), but it is not certain that the latter are not campaniform organs.

Plate organs have been noted and described in several species of Coleoptera. Vom Rath (1888) says that the antennal lamellæ of *Cetonia aurata* are thickly beset with them (" membrane canals "), and he gives the form of the cuticular parts of one in section as shown at C of figure 23. Ruland (1888) records plate organs on the antennæ of *Necrophorus vespillo,* and figures the chitinous parts as shown at D. Hochreuther (1912) describes plate organs on the antennæ, mandibles, and maxillary palpi of *Dytiscus marginalis* under the name of " chalice-form organs," the term referring to the shape of the cuticular canal beneath the plate in vertical sections (fig. 23 B, C). He says that the plates in *Dytiscus* are extremely small, being from 6 to 8 microns in diameter, and that those of the antennæ number from 4,500 to 5,000. They have the same essential structure (B) as those of the antennæ of Hymenoptera (I, K) except that the margin of each is deeply inflected. The histological elements of the plate sensilla of the Coleoptera have not been well distinguished, though each is innervated through a group of sense cells.

It is in the Hymenoptera that the sensilla placodea are best known and, apparently, best developed. They have been found only on the antennæ in this order. In *Cynips* and *Ophion,* according to Ruland (1888), the plates are greatly elongate in form (fig. 23 E). The outer surface in *Cynips* is slightly elevated above the general surface of the antenna and is surrounded by a deep groove; the under surface presents two longitudinal ridges (F). In *Ophion* (G) the plate is a thin, arched, chitinous membrane, beneath which project two ridges from the walls of the cuticular canal, leaving only an axial slit open between them. In *Vespa crabro* the plates are also elongate and narrow (H), and each is surrounded by a deep furrow, as shown well in a cross-section (I).

In the honeybee the plate organs are closely distributed over the entire inner and ventral surfaces and on the dorsal surface of the distal half of the last eight segments of the flagellum of each antenna. There are about 30,000 on both antennæ of the drone, 5,000 to 6,000 in the worker, and 2,000 to 3,000 in the queen. In the Vespidæ, solitary bees, and bumblebees, according to Schenk (1903), the plate organs are but little more numerous in the males than in the females. Each plate, in the honeybee, is elliptical in shape (fig. 23 J) and from 12 to 14 microns in longest diameter, which is lengthwise on the antenna. The surfaces of the plates are flush with the antennal wall, but each plate is surrounded by a line of clear chitin (*a*) which may be marked by a slight groove in some cases, but is certainly not excavated to form a deep furrow around the plate, as indicated in figures by Ruland (1888), Schenk (1903), and McIndoo (1922). Within the margin of the plate is a second concentric light line (*b*), due to a submarginal groove on the inner surface (K, *b*). The cuticular canal beneath the plate is large but contracted proximally (K), its wall nearest the base of the antenna being approximately vertical while the other slopes inward toward the antennal base.

The inner structure of a plate sensillum in the Hymenoptera is similar to that of the pegs and the thin-walled hairs of the chemoreceptive series (fig. 18). In a plate organ of the honeybee (fig. 24 A) most of the space in the cuticular cavity beneath the plate is occupied by a large cap cell (*CCl*) which projects below the inner surface of the cuticula. On the side toward the base of the antenna the cap cell is perforated by a tubular canal which contains the distal parts of the enveloping cell (A, B, *ECl*) and the terminal strand (*TS*) of the sense cells. The strand expands proximally into the compact, cylindrical bundle or fasciculus (*Fas*) of sense cell proc

esses, which lies in a vacuole (Vac) within the enveloping cell. Cross-sections show that there is probably only one enveloping cell to each sensillum (C, ECl), though both Vogel (1923) and the present writer in a former work (1925) have shown two. The sensilla lie so close together that, in sections cut vertical to the surface, it is impossible to distinguish the cells of neighboring organs. The sense cells (A, $SCls$) of all the sensilla of the antennal organs of the honeybee form one continuous mass of sensory cells beneath the normal hypodermis, nearly surrounding the lumen of the antenna,
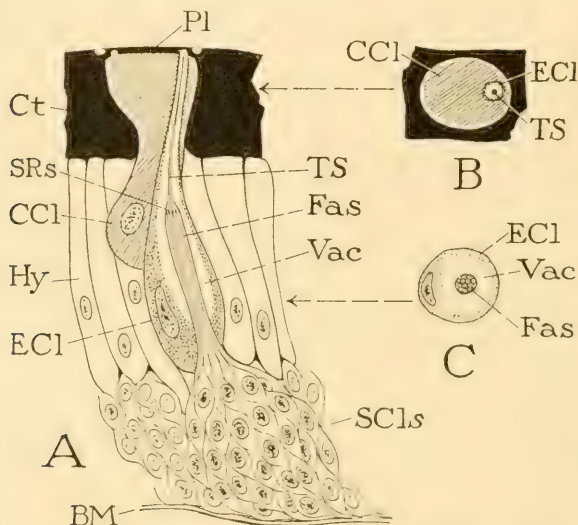
FIG. 24.—Diagrammatic structure of a sensillum placodeum of *Apis mellifera.*

A, vertical longitudinal section. B, cross-section just beneath plate. C, cross-section near base of enveloping cell.

being absent only along the outer side where there are no sense organs.

It would be useless to review here all the opinions that have been held concerning the function of the sensilla placodea, since there is little direct evidence connecting any specific sense with these organs. Some writers have regarded them as having an auditory function, others have sought to explain them as organs for perceiving air pressure, and still others have believed that they are organs of smell. Since it seems now pretty well attested that the principal seat of the olfactory sense in bees is located on the antennæ, the most characteristic organs of the antennæ might be supposed to be the organs of smell. Suspicion, therefore, falls upon the plate organs. Yet, these

organs would appear to be poorly adapted for the reception of olfactory stimuli, and the responsibility might be shifted to the numerous small, thin-walled hairs which cover the flagella. The plates themselves are about 1.5 microns in thickness, but the surface over the inner groove is not more than half a micron thick. A liquid might, therefore, exude through the groove, spread over the surface of the plate, and absorb odor substances, as some writers have suggested, but, as mentioned before in the case of other supposed olfactory organs, no one has observed the presence of any such liquid.

VII. THE CHORDOTONAL ORGANS

The sensory organs of insects known as the *chordotonal organs* consist of bundles of simple sensilla, each of which comprises a cap cell, an enveloping cell, and a single sense cell. The distal end of the organ is attached to the cuticula of the body wall, but there is no specially differentiated external receptive part, though the point of attachment may be marked by a pit, a thickened disc, or a nodule of chitin. The base of the organ is usually connected with the hypodermis, often by a special ligament. A typical chordotonal organ, therefore, is suspended between two points of the body wall. The organs are frequently associated with enlarged parts of trachæ, or with tracheal sacs, and in some cases with membranous tympana of the body wall.

In form, a chordotonal organ is usually elongate or fusiform (fig. 25); its elements may, however, constitute an oval mass (fig. 27 B, *SB*), they may spread out in the form of a fan (fig. 28, *SgO*), or they may be arranged serially (fig. 28, *TmO*). The cap cell is generally elongate (fig. 26, *CCl*), sometimes attenuate and tapering to the point of attachment (fig. 25), but it may be short and thick (fig. 29 B, *CCl*). The enveloping cell apparently does not reach to the cuticula through the cap cell (fig. 26, *ECl*), but its distal end is buried in the base of the latter. The sense cell is of the usual oval or fusiform shape (*SCl*); its long distal process (*d*), inclosed within the enveloping cell, has a well-developed sense rod, or scolopala (*SR*) at its end. The chordotonal ligament, when present (fig. 25, *d*), is inserted on the bases of the sense cells, and attached distally to the hypodermis at a point opposite the attachment of the cap cells.

The structure of the chordotonal ligament is not well understood. According to Graber (1882), the ligament of the chordotonal organs of the larva of Corethra has the general appearance of a nerve, appearing to be a thin-walled tube filled with a homogeneous granular mass, the membranous walls of which are continuous with the

sheath of the nerve. Hess (1917) says the ligament in the organs of Cerambycid larvæ is probably a connective tissue originating from the hypodermis; but Eggers (1920) claims that in the thoracic chordotonal organs of adult Lepidoptera it is composed exclusively of tracheal epithelium. The ligament may be long and slender, or it may be reduced in length or lacking entirely; in the latter case the sense cells of the organ are attached to the hypodermis by a few intervening cells, or they rest upon it directly.

The scolopalæ, or sense rods of the chordotonal organs, have been described in the section treating of the sense rods in general (page 35). In length they vary from a few microns to as much as 23
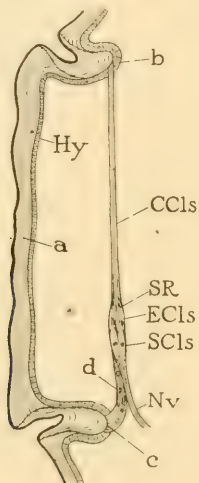
FIG. 25.—Chordotonal organ of larva of *Monohammus confusor*, in horizontal section of a pleural disc of an abdominal segment (Hess, 1917).

a, wall of pleural disc; *b*, attachment of cap cells to infolded cuticula at posterior end of disc; *c*, attachment of chordotonal ligament (*d*) to infolded cuticula at anterior end of disc; *d*, chordotonal ligament.

microns in different organs; some are slender and cylindrical (fig. 15 F, H, I), others are short (E, G) or bulb-like in form (M). The walls are usually ribbed internally (I, K, *r*); the apical body of the head (*AB*) is always conspicuous in stained specimens, and the axial fiber (*AxF*) is attached to it. Often there is no apparent connection between the scolopala and the cuticula of the body wall, but in most organs a distinct terminal fiber (fig. 15, F, fig. 26, *t*) extends from the apex of the scolopala through the cap cell to the cuticula; in a few the fiber appears to end before reaching the cuticula.

Scolopalæ were discovered first in the tympanal organs of Orthoptera by von Siebold (1844); they were found next in organs of the wing bases of Coleoptera and Diptera by Leydig (1860). The first concise description, however, of the scolopalæ and of the structure and distribution of the chordotonal organs in insects and in different parts of the insect body was given by Graber (1882) in an extensive paper on the chordotonal organs, which has served as a basis for all subsequent studies of these organs. Graber, however, embraced in his definition of " chordotonal " organs all sense or-
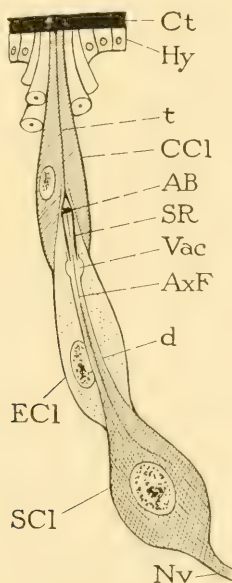
Fig. 26.—Diagrammatic structure of a single sensillum of a chordotonal organ.

Presumably the sense cell (*SCl*) and the enveloping cell (*ECl*) extend to the cuticula, at least in a formative stage, but in the adult organ they appear to end in the base of the cap (*CCl*).

gans " in which there is present a nerve-end structure similar to the well-known ' auditory rod ' of the Orthoptera," and he included in his descriptions not only the organs which we now call " chordotonal " but also the campaniform organs of the wing bases.

It is clear that the chordotonal organs cannot be defined as " scolopophorous " organs, as is still done by some modern writers, since it is now evident that a scolopala or sense rod of some sort is present in the majority of insect sense organs. The term " chordotonal," however, may be retained inasmuch as it has become well fixed by universal usage, though it carries an auditory implication which probably does not apply to chordotonal organs in general.

Since the time of the earlier writers on the chordotonal organs—von Siebold, Leydig, Graber—our knowledge of these structures has been greatly augmented through the work of many other investigators. Among the latter should be mentioned von Adelung (1892), Herbig (1902), Janet (1904), Schwabe (1906), Berlese (1909), Schön (1911), Vogel (1912), Lehr (1914), Erhardt (1916), Hess (1917), Eggers (1920), and McIndoo (1922); but the student may obtain a complete list of papers on the chordotonal organs from the bibliographical references in the works of these authors.

Chordotonal organs are widely spread in insects, but they have not been recorded in other members of the Arthropoda. In adult insects they occur in the head, the thorax, the abdomen, the antennæ, the legs, and the wing bases; in larvæ they occur mostly along the sides of the abdomen, but have been described also in the labium, in the legs, and even in the tarsi.

The characteristic chordotonal organs of larval insects are those found in the abdomen, where a pair, one organ on each side, occurs in each of the first seven or eight segments. Each organ is stretched longitudinally between points on the anterior and the posterior parts of the lateral wall of the segment, sometimes between infoldings of the cuticula (fig. 25), though usually no external characters mark the site of the organ. The anterior attachment (c) is made by the chordotonal ligament (d), the posterior one (b) by the ends of the cap cells ($CCls$). The chordotonal nerve (Nv) turns mesially from the sense cells ($SCls$) to go to the ventral ganglion of the segment. Organs of this type were described by Graber (1882) in aquatic larvæ of Coleoptera, in the caterpillars of *Carpocapsa* and *Tortix*, in larvæ of Diptera (*Corethra, Culex, Simulium, Ptychoptera, Tabanus*), and in the larva of a sawfly (*Nematus*). Hess (1917) gives a particular account of the chordotonal organs of Cerambycid larvæ, showing that the pleural discs along the sides of these insects, on the first eight abdominal segments, mark the points of their attachment, though the presence of chordotonal organs within these discs was first noted by Schiödte (1869).

In adult insects, the chordotonal organs are principally organs of the legs and the wing bases, but they occur also in the head, the antennæ, the thorax, and the abdomen; those connected with the abdominal and leg tympana of Orthoptera are the best known.

The so-called "ear" of the grasshopper, the tympanal chordotonal organ located on the side of the first abdominal segment (fig. 27), is too well known to need a special description here. On the inner surface of the tympanum (B, Tm) is a small cellular body

(*SB*) first discovered by Müller (1826), and sometimes known as the organ of Müller, which consists of a mass of scolopophorous sensilla. Some are attached by short thick cap cells to a peg-like invagination of the tympanum (*c*), others by long cap cells to a pear-shaped thickening of the membrane (*a*). The nerve of the organ (*Nv*) goes to the ventral ganglion in the third thoracic segment. Three large air sacs are applied to the inner surface of the tympanum. The large membranous tympanum, set in a cavity of the body wall, suggests an ear drum, and on this suggestion, rather than on concrete evidence, is based the persistent idea that this
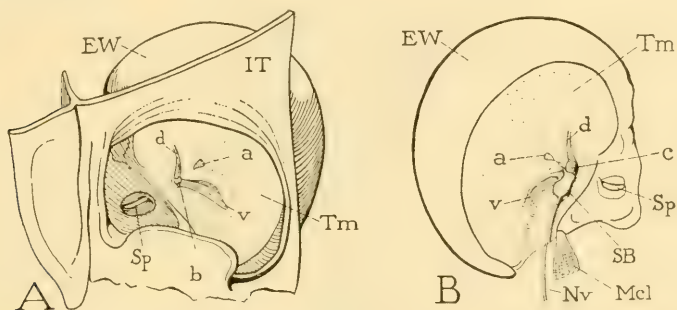
FIG. 27.—The " ear " of a grasshopper (*Dissosteira carolina*).

A, external view of tympanum (*Tm*) on side of first abdominal tergum (*IT*) : *a*, pear-shaped thickening of tympanum; *b*, external pit forming peg on inner surface (*B, c*) ; *d*, dorsal supporting arm of internal peg; *EW*, wall of external tympanal cavity; *IT*, lateral part of first abdominal tergum; *Sp*, first abdominal spiracle; *Tm*, membranous tympanum; *v*, ventral arm of internal peg.

B, inner view of tympanum and wall of tympanal cavity; *c*, hollow chitinous peg projecting from tympanum and supporting the sensory body (*SB*) ; *Mcl*, tensor muscle of tympanum; *Nv*, chordotonal nerve; *SB*, chordotonal sensory body, a branch of which goes to the pear-shaped thickening (*a*). Other letters as on A.

chordotonal organ of the grasshopper is an organ of hearing, and, by inference the idea that all chordotonal organs have an auditory function.

In the fore tibiæ of the Tettigoniidæ (Locustidæ) and the Gryllidæ, there are chordotonal organs also associated with tympana, but not attached to them. The two tympanal areas at the upper end of each tibia lie at the sides of two divisions of the principal leg trachea (fig. 28, *aTr, pTr*), one anterior, the other posterior (oriented thus with the leg extended at right angles to the body). In the Tettigoniidæ (figs. 28, 29) the tympana (*aTm, pTm*) are covered by folds of the leg wall, forming tympanal cavities (*TC, TC*) opening through slits toward the outer surface of the leg (fig. 29, *e, e*). In

the Gryllidæ the tympana are exposed, but the anterior one is small and more or less rudimentary and is separated from the neighboring trachea by an internal chitinous plate.

In the Tettigoniidæ there are three chordotonal organs in each front tibia (fig. 28). The uppermost (SgO) is known as the subgenual organ, since it lies just below the "knee," or femero-tibial articulation.
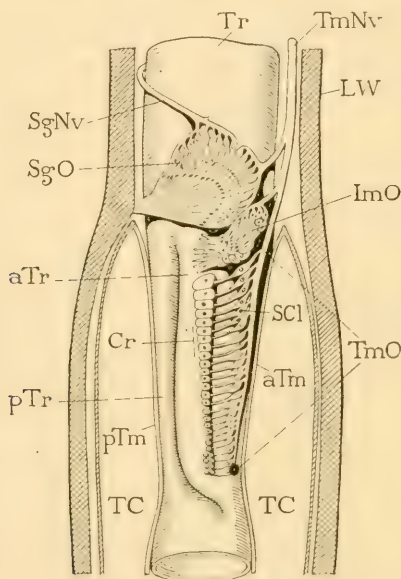
Fig. 28.—Chordotonal organs in the right front tibia of a Tettigoniid (*Decticus verrucivorus*) exposed by removal of outer wall of leg (diagrammatic and simplified from figure by Schwabe, 1906).

aTm, anterior tympanum; *aTr*, anterior tracheal branch; *Cr*, crest of tympanal organ; *ImO*, intermediate organ; *LW*, wall of leg; *pTm*, posterior tympanum; *pTr*, posterior tracheal branch; *SCl*, sense cells of tympanal organ; *SgNv*, subgenual nerve; *SgO*, subgenual organ; *TC, TC*, tympanal cavities opening through slits on exterior of tibia (fig. 29A, *c, c*); *TmNv*, tympanal nerve; *TmO*, tympanal organ; *Tr*, main leg trachea.

The second is termed the intermediate organ (ImO) because it lies between the upper ends of the tympana. The third is the tympanal organ (TmO) or the so-called "crista acoustica" which forms a crest along the outer surface of the anterior trachea, between the two tympana.

Two separate nerves enter the fore leg, according to Schwabe, from the ventral ganglion of the first thoracic segment. One is the usual leg nerve, the other is a special tympanal nerve. The former follows the ventral wall of the leg and, in the femero-tibial articula-

tion, gives off a sensory branch (fig. 28, *SgNv*) that innervates the upper part of the subgenual organ. The tympanal nerve (*TmNv*) consists entirely of sensory fibers. It follows the anterior wall of the leg and, in the upper part of the tibia, gives off branches to the lower part of the subgenual organ (*SgO*) and to the intermediate organ (*ImO*), while its main trunk ends in fibers to the sense cells of the crest (*TmO*).

The subgenual organ (*SgO*) has the usual chordotonal structure, and is probably the homologue of the chordotonal organ that occurs in a similar position in the legs of some other insects. It is attached by the converging ends of its elongate cap cells to the posterior wall of the leg just above the posterior tympanum. Its sensilla radiate inward and upward, like the ribs of a fan, in cross-section.

The intermediate organ (*ImO*) consists of an irregular mass of sensilla lying at the upper end of the crest on the outer surface of the anterior trachea. Its distal end is attached to the outer wall of the leg by a strand of fibrous and cellular tissue (not shown in the figure).

The tympanal organ (*TmO*) is the organ of particular interest in the Tettigoniid leg, because its sensilla are arranged serially and their outer ends, containing the scolopalæ, form a crest-like ridge (*Cr*) along the outer surface of the anterior trachea (*aTr*), in which the cap cells and scolopalæ decrease in size from above downward. This arrangement, suggesting that the receptive elements are graded to respond to different wave lengths of sound, has strengthened the general belief that the organ has an auditory function.

The sense cells of the tympanal organ lie along the anterior margin of the trachea, in the angle between the latter and the anterior tympanum (figs. 28, 29 A, B, *Scl*) where each receives a fiber from the tympanal nerve trunk (fig. 28, *TmNv*). The distal processes of the sense cells, and the basal parts of the enveloping cells extend posteriorly on the surface of the trachea to its middle where they turn abruptly outward in the crest (*Cr*). The ridge of the crest is formed by the cap cells (fig. 29 B, *CCl*). The crest is covered by a " crest mass " (*a*), which Schwabe (1906) says consists of a fibrous matrix in the meshes of which there is a clear substance and a varying number of scattered cells. Finally, both the crest and the intermediate organ are ensheathed in a delicate membrane (*Mb*) reflected on one side from the inner wall of the anterior tympanum and on the other from the wall of the trachea.

The tympanal chordotonal organ of the Tettigoniidæ appears, at first sight, to differ from all other sense organs in having its cap cells

and sense rods directed away from the point of attachment, free from any connection with the body wall. The crest, however, as pointed out by Schwabe, is not distinctly separated from the intermediate organ at its upper end. Both are surrounded by the same membranous sheath, and von Adelung (1892) has shown that there is a cord-like strand of fibrous and cellular tissue that connects the intermediate organ with the outer wall of the leg, where it is inserted upon the cuticula between cells of the hypodermis. It seems probable, therefore, that this strand represents the true origin of these organs
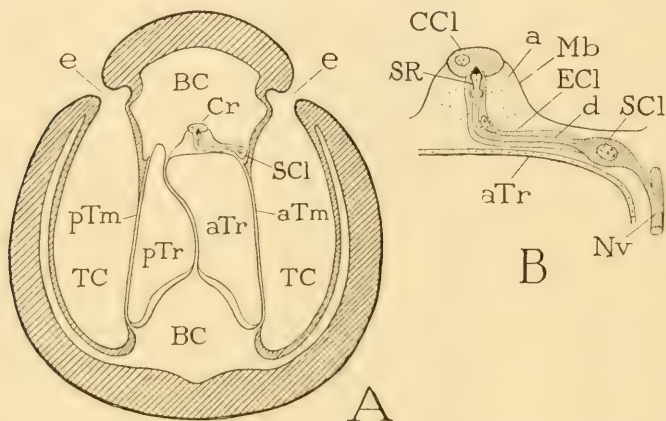
FIG. 29.—Sectional views of tympanal chordotonal organ in front leg of *Decticus verrucivorus.*

A, cross-section of upper end of tibia (simplified from Schwabe, 1906): *BC, BC,* inner cavity of leg; *e, e,* outer openings of tympanal cavities (*TC, TC*); other lettering as in fig. 28. The two tracheal branches (*aTr, pTr*) lie between the tympana (*aTm, pTm*), with chordotonal crest (*Cr*) on outer surface of anterior trachea.

B, diagrammatic cross-section of the crest and a sense cell of the tympanal organ: *a,* "crest mass" inclosing the sensilla; *aTr,* wall of anterior tracheal branch; *CCl,* cap cell; *d,* distal process of sense cell; *ECl,* enveloping cell; *Mb,* membrane covering the crest; *Nv,* tympanal nerve; *SCl,* sense cell; *SR,* sense rod, or scolopala.

in the body wall, and that the position of the crest on the surface of the trachea is a secondary one.

In the crickets (Gryllidæ) only two chordotonal organs have been described in the fore tibiæ, a subgenual organ, and one on the trachea corresponding with the crest of the Tettigoniidæ; but the latter is shorter and more fan-shaped than in the katydid species that have been studied. (Herbig, 1902; Berlese, 1909.)

In the Hymenoptera a subgenual chordotonal organ occurs in all the legs of species that have been examined for it, including a sawfly, ants, wasps of the family Vespidæ, Bombus, and the honeybee. (Janet, 1904; Schön, 1911; McIndoo, 1922).

In the wing bases, including the halteres of Diptera, it is now known that chordotonal organs are of frequent occurrence. The studies of Pflugstaedt (1912), Vogel (1912), Lehr (1914) and Erhardt (1916), show that they are present in this location in Odonata, Neuroptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera, but absent in Orthoptera and Hemiptera. Usually, each wing base contains only one or two organs, though Erhardt reports the presence of seven in the base of each front wing of Chrysopa, and six in each hind wing. The distal ends of the wing organs are in all cases attached to the ventral surfaces of the wing bases.

In other parts of the body, chordotonal organs have been described in various situations in different insects: in the head of ants and bees (Janet, 1894, 1911), in the antennæ of *Dytiscus* (Lehr, 1914), in the ventral part of the prothorax of ants (Janet, 1894), in the posterior part of the thorax of many Lepidoptera (Eggers, 1920), and in the first abdominal segment of the cicada (Vogel, 1923 *a*). Judging from the number of chordotonal organs already known in insects, and from the diversity of their positions, it is likely that further studies will show a still wider distribution of them in a greater number of species. It would be surprising, in fact, if they should not be found eventually in most of the species in all orders.

The development of the chordotonal organs in the legs of the honeybee has been studied by Schön (1911). In the worker bee, according to Schön's account, on the eighth day after the laying of the egg, which is the fifth day of the larval stage, there appears in the tibia of the inverted imaginal leg, just below the femero-tibial joint, a small ingrowth of the hypodermis over an invagination of the cuticular wall of the leg. This ingrowth becomes the chordotonal organ. On the ninth and tenth days its cells begin to differentiate, the sense cells being first distinguishable, segregated at the inner end of the mass. From them a short process extends inward which will later unite with the chordotonal branch of the leg nerve. The imaginal bud of the leg is everted on the eleventh day. On the thirteenth day there still remains a remnant of the cuticular invagination; the external opening is finally closed, but the internal part remains as a hollow within the mature organ. On the seventeenth day the organ is completed; on the twenty-first day the young worker emerges from its cell. From this account it is clear that the chordotonal organ is a modification of the body wall, as are all the other sense organs, and that its cells, including the sense cells, are differentiations of the hypodermis.

Concerning the function of the chordotonal organs nothing definite can be said. In the text books the chordotonal organs are presented as "organs of hearing." It is certain, however, that the perception of sound has not been proved to be connected with any of them, and those organs situated within the legs, the wing bases, and various regions of the body where they are affixed to solid parts of the body wall, even though they may be associated with enlarged trachæ, seem poorly adapted for acoustic purposes. On the other hand, the internal position of the organs suggests that they must have some function connected with the workings of internal parts of the body. Following this idea, the discussion of Eggers (1923) on the possible uses of the chordotonal organs leads to conclusions more convincing than any other yet presented bearing on the function of these enigmatical structures peculiar to insects.

Eggers points out that most of the movements made by insects result in rhythms. Especially is this true of the action of the wing mechanism, which sets the whole body into rapid vibration; but also the motions of the antennæ and the legs tend to become rhythmical, while the movements of respiration, the pulsations of the heart, the bodily motions of locomotion in certain aquatic larvæ are all of a rhythmic nature. Since rhythm, then, is such a characteristic feature of muscular activity in insects, it would seem that there should be special organs for registering it and for regulating the action of the muscles that produce it. The chordotonal organs suggest themselves at once as organs adapted for this purpose and as the only organs that could serve in such a capacity. According to this idea, therefore, the chordotonal organs are to be regarded as rhythmometers.

Finally, it is conceivable, as suggested by Eggers, that if a chordotonal organ is connected with a thin membrane of the body wall, or is sufficiently delicate in its construction, it might be responsive to motions of the surrounding medium; i. e., to vibrations of air or water, and hence might act as a receptor of sound waves. Thus, for example, the highly developed organ of Johnston in the antenna of the Culicidæ (fig. 31 B) or the tympanal organs of the Orthoptera may be organs of hearing.

VIII. THE ORGAN OF JOHNSTON

Located in the second segment of the antenna of most insects, the segment commonly distinguished as the pedicel, is the sense organ that has long been known as the organ of Johnston. Structurally it scarcely deserves to be placed in a class by itself, since it appears

to be only a simplified chordotonal organ, but inasmuch as it possesses distinctive features and probably has a specific function, there is no particular reason for its demotion.

The organ of Johnston consists of bundles of elongate sensilla forming a cylindrical sheath about the antennal nerve trunks within the pedicel. The distal ends of the sensilla are attached in groups, corresponding with the bundles, to the articular membrane between the second and third segments of the antenna. Usually the points of attachment of the sensilla groups are marked by pits in the membrane, which form a circle at the end of the pedicel. The base
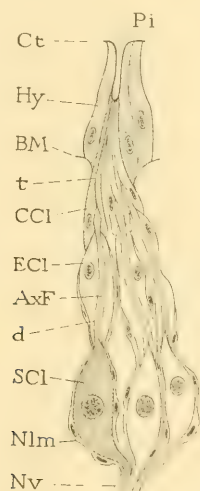
FIG. 30.—Group of sensilla of organ of Johnston of mature pupa of a wasp, *Vespa crabro* (Berlese, 1909).

of the organ is connected by nerve fibers with the main antennal nerves.

The organ was described first in the antenna of a mosquito (*Culex*) by Johnston (1855), who gave, however, but a brief account of its structure. Later it was more thoroughly investigated by Child (1894) who found it in ten of the principal orders of insects. More recently the organ named after Johnston has been studied by Berlese (1909) and by Lehr (1914 *a*). The orders of insects in which an organ of Johnston is now known to occur are the Odonata, Orthoptera, Hemiptera, Anopleura, Neuroptera, Coleoptera, Trichoptera, Lepidoptera, Diptera, and Hymenoptera.

The structural details of the organ of Johnston have been less studied than have those of the true chordotonal organs, but there appears to be no radical difference between the two sets of organs.

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Berlese (1909) gives a drawing of a group of sensilla from the organ of Johnston of a wasp, *Vespa crabro,* taken from a mature pupa, in which he depicts the usual chordotonal structure (fig. 30), each sensillum being shown to consist of a cap cell (*CCl*), an enveloping cell (*ECl*), and a sense cell (*SCl*). The sense cell has a long neck extending apparently through the enveloping cell into the base of the cap cell, where it ends in a scolopala-like rod attached by a long distal fiber from its apex to a cuticular pit between the second and third antennal segments. Child had noted the presence of rods in the organ of Johnston of the mosquito, but his description and drawing (fig. 31 B) do not show clearly their relation to the sense cells. Lehr describes the organ in the antenna of *Dytiscus marginalis* and his account of the structure of the sensilla agrees essentially with Berlese's figure of that in the wasp. The enveloping cells, according to Lehr, are not as well defined as in a typical chordotonal organ; the scolopalæ are simple fusiform rods, each continued at its apex into a terminal filament attached to the cuticula. Neither writer, however, shows the presence of an apical body in the scolopalæ of the organ of Johnston or ribs in their walls, though each rod is traversed by an axial filament.

An organ of Johnston of a primitive nature is described by Zawarzin (1912) and Eggers (1923) in the antenna of a dragonfly larva. The organ here appears to consist merely of a circle of elongate sense cells in the second antennal segment, the cells being attached by their distal ends to the articular membrane between this segment and the third. According to Eggers there are no enveloping cells present in this organ, and scolopalæ are not differentiated in the sense cells, the distal parts of the latter having a fibrous texture.

In other insects the organ of Johnston varies much in its development. Its bundles of chordotonal-like sensilla usually form a simple cylinder within the pedicel of the antenna, as shown in longitudinal section at A of figure 31. (The details of structure are probably not well illustrated in this figure.) The organ reaches its highest degree of development in the males of the families Chironomidæ and Culicidæ, in which the second segment of the antenna is greatly enlarged. The well-known illustration from Child (fig. 31 B) gives a general idea of the appearance of the organ of Johnston in a longitudinal section through the base of the antenna of a male of *Corethra (Mochlonyx) culiciformis.* The sensilla of the organ are here not attached in the usual way to pits of the articular membrane between the second and third segments; the membrane is chitinized to form a circular plate (*a*) attached to the base of the third segment (*3Seg*), from

the outer edge of which 70 to 90 slender chitinous prongs (*b*) radiate into the lumen of the pedicel and carry the distal attachments of the sensilla. The sense cells form a thick peripheral layer in the pedicel (*2Seg*), the distal parts of the sensilla converging toward the supporting arms, while the nerves of the organ diverge from the main antennal trunks (*Nv*) in the first segment (*1Seg*).

The development of the organ of Johnston in *Corethra* is described by Child as follows: Immediately after the last molt of the
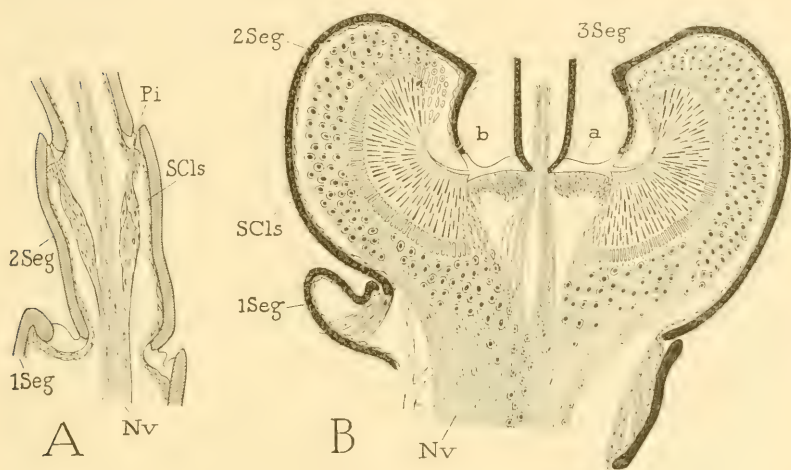
FIG. 31.—The organ of Johnston in simple and complex form (Child, 1894).

A, longitudinal section through base of antenna of *Melolontha vulgaris,* showing two bundles of sense cells (*SCls*) with terminal processes attached to pits (*Pi*) in articular membrane between pedicel (*2Seg*) and third antennal segment.

B, highly developed organ of Johnston in pedicel (*2Seg*) of antenna of *Corethra culiciformis,* longitudinal section. The terminal processes of the sense cells (*SCls*) here attached to prongs (*b*) from circular chitinous plate (*a*) on base of third segment (*3Seg*).

larva the hypodermis of the second antennal segment forms a fold, growing from before backward, that surrounds the antennal nerve. The outer layer of the fold remains thin, but the inner layer thickens by a multiplication of its cells. The cells of the inner layer then become elongate, but at first are all alike; later they differentiate into sense cells and rod-bearing cells. Nerve fibers from the central nerve axis finally become attached to the bases of the sense cells. This account is probably somewhat crude, but it shows at least that the organ of Johnston is differentiated from the hypodermis as are all other insect sense organs.

Some writers classify the organ of Johnston as an auditory organ, but there is little evidence in support of the idea that it is a sound receptor in any insect. From its widespread occurrence in insects, however, we may infer that it is an organ of importance, and its constant position suggests that it must have some specific sensory function. Its structure in the Chironomidæ and Culcidæ, especially the union of the supporting plate (fig. 31 B, *a*) with the base of the third antennal segment (*3Seg*), suggests that the organ in these families is an apparatus for registering the movements of the flagellum. It may, therefore, be supposed to be perceptive to slight air motions, but whether to waves of sound or not is still to be questioned.

IX. THE EYES

The word " eye " is used in a general sense for any specific organ that is sensitive to light falling upon it and capable of transmitting the resulting stimulus to the central nervous system. An eye is primarily a light-perceiving organ, or photoreceptor, and it is not to be assumed that all eyes are capable of registering impressions of form, color, or motion in external objects. The effect of the light stimulus on the organism must vary with the structural development of the eye and of the visual centers of the nervous system.

The eyes of insects are usually classified as *simple eyes,* or *ocelli,* and *compound eyes*. The compound eye constitutes a definite type of organ common to insects and crustaceans, and is most probably the primitive eye of these two groups. The ocelli, on the other hand, are a heterogeneous group of photoreceptive organs comprising several distinct kinds of eye structures, which probably either have had separate origins or have followed separate lines of development from a primitive type. Only a brief description of the eyes of insects will be given here, because a complete treatment of the subject would involve a discussion too long for the present paper. A reference to the many valuable works now at hand on the structure of insect eyes must also be omitted. The histology of the eyes is better known than that of other insect sense organs, but still there is much that has not found its way into any general review of the morphology of the visual organs.

The fundamental elements in all the varieties of insect eyes are innervated photoreceptive cells of hypodermal origin. These cells correspond with the sense cells of the other sense organs, and may be designated the sense cells of the ocular sensillum. Associated with them are other cells derived from the hypodermis, but these have so little in common with the enveloping cells of the other sense or-

gans that any theory which would derive an ocular sensillum from that of a sensory hair, as that proposed by Patten (1890), is too far-fetched to be convincing. The number of sense cells in a single eye varies from two cells to many thousand in the different types of insect eyes. All the sense cells of one eye constitute what is generally regarded as the retina of the arthropod eye. The optic lobes of the brain (fig. 4, *OpL*), upon which the compound eyes rest, are parts of the central nervous system and do not contain the precipient elements of the eye, as in vertebrates. Each retina cell is traversed by fibrils which are continuous proximally with the ocular nerve, and which end distally in a definite marginal part of the cell, which part becomes the sensitive area of the cell. This area commonly has the appearance of being vertically striated or formed of a fringe of minute thread-like rods. It is known as the *rhabdomere* because it often combines with the corresponding borders of neighboring cells to form a crystalline visual rod called a *rhabdom*. Retina cells thus grouped about a rhabdom constitute a composite retinal element known as a *retinula*. The retinal cells rest upon the basement membrane, which is perforated by the fibers of the optic nerves.

The same question arises regarding the innervation of the eyes as with the other sense organs; *i. e.,* whether the ocular nerve fibers grow outward and penetrate the retinal cells, or whether they originate in the retinal cells and grow inward to the optic lobes. Some writers are positive in asserting that the second process of growth takes place with the compound eyes, that the growth of the nerves can be followed in the development of the eye from the retinal cells inward to the ganglia of the optic lobes. If this is true, then the hypodermal retinal cells are the cytons of the peripheral ocular nerve fibers.

THE COMPOUND EYES

The well-known lateral compound eyes of Crustacea and Insecta consist, in their typical form, of groups of ocular sensilla or *ommatidia*. The number of ommatidia in a single eye in different insects is usually between a few hundred and 20,000, but in some the number is estimated to be as high as 30,000. In aberrent or degenerate types there are but a few ommatidia or even only one ommatidium.

The outer surface of each ommatidium consists of the cuticular *cornea* (fig. 32 A, B, *Cor*), which is commonly thickened to form a lens. Beneath the cornea of some of the more primitive insects and in crustaceans are two *corneagenous cells* (A, *CorCl*), but in the mature eye of most insects (B) these cells are usually withdrawn

from the normal position and from contact with the central part of the cornea. Under the corneagenous cells, or directly beneath the cornea when the corneagenous cells are displaced, are four cells, sometimes called the cells of Semper, that usually unite to form a conical crystalline body (Cn) having its apex directed inward. The four component cells are, therefore, usually known as the *cone cells*. Proximal to the cone or the cone cells are the retina cells (Ret) of
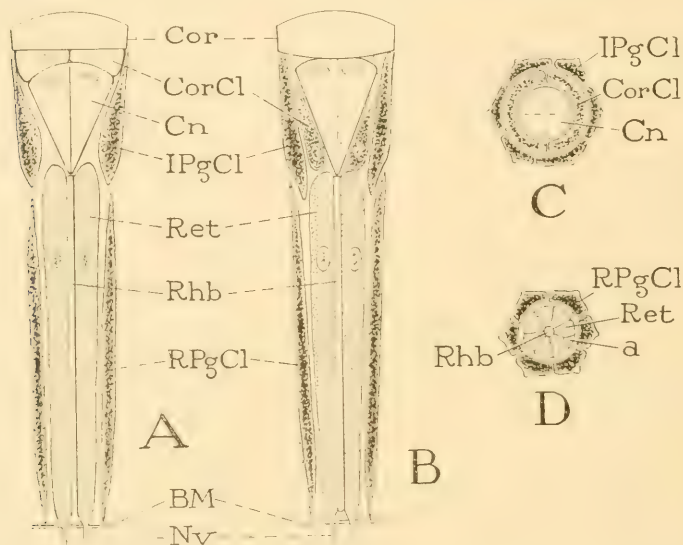
FIG. 32.—Diagrammatic structure of an ommatidium of the compound eye.

A, type of eye in which the corneal cells (*CorCl*) lie immediately beneath the cornea, exemplified by the adult eye of *Machilis* and of many crustaceans and by the immature eye of some insects.

B, type of eye usual in adult insects in which the corneal cells (*CorCl*) have become pigment cells surrounding sides of cone.

C, cross-section of ommatidium through cone, showing the two corneal pigment cells (*CorCl*) surrounding sides of cone.

D, cross-section of ommatidium through retinula, showing rudimentary eighth retinula cell (*a*) at surface of retinula and taking no part in formation of rhabdom (*Rhb*).

the ommatidium, which typically are slender and elongate, and constitute a retinula with an axial rhabdom (Rhb) directly beneath the apex of the cone. The primitive number of retinula cells in each ommatidium is probably eight, but generally one is aborted or crowded away from the axis (D, a), leaving seven as the typical number taking part in the formation of the rhabdom. The lower ends of the retinulæ rest upon the basement membrane (BM), and the fibers of the optic nerves (Nv) entering the optic lobes of the brain penetrate the membrane to end in the ganglia of the lobes.

The compound eyes are well developed in nearly all adult insects; their absence is to be regarded as due to a degeneration of the organs and not as representing a primitive eyeless condition. In the Collembola, and in Lepisma of the Thysanura, the compound eye does not have the typical form. In the Collembola there are from 1 to 12 small eyes on each side of the head in some species, and in ·Lepisma a group of 12 similar eyes on each side. These eyes have an external resemblance to the scattered lateral ocelli of caterpillars and some other larvæ of the higher insects, and in internal, structure they are in some ways also similar to these eyes; but they have other characters that are distinctive of compound eyes. Their structure in general is that of a primitive compound eye with aberrant features, and they are, therefore, probably to be regarded as degenerate ommatidia of compound eyes. This conclusion is strengthened by the fact that in *Machilis,* another member of the Thysanura, the lateral eyes are distinctly of the typical compound eye type (fig. 32 A), and retain the primitive and crustacean character of having the corneagenous cells beneath the lens.

In the compound eye of most other insects the corneagenous cells, as already noted (fig. 32 B, *CorCl*), withdraw from beneath the cornea in the mature stage and take positions at the sides of the cone, where they acquire a deposit of pigment, and become the cells known as the primary pigment cells, or *corneal pigment cells.*

The four cone cells (fig. 32 C, *Cn*), when they form a typical cone, fuse completely; their protoplasm becomes converted into a clear hyaline substance, and their nuclei remain in the outer or basal part of the cone (A, B). Eyes with a cone of this type are designated *eucone* eyes. In some insects, however, especially in the Diptera, the cone cells secrete a transparent substance which forms a conical mass beneath the cornea held between the surrounding pigment cells, but the cone cells remain distinct with their nuclei beneath the vitreous mass. Eyes with an imperfect cone of this kind are distinguished as *pseudocone* eyes. In some of the Diptera, again, the eyes are of an *acone* type, the cone cells remaining distinct without forming a vitreous body of any sort.

The retinulæ cells (fig. 32 A, B, *Ret*) extend from the cone, sometimes embracing its apex, to the basement membrane. In eyes of simpler construction they form one layer of cells, but their arrangement is subject to much variation in the various modifications of the retinular structure in different insects. The nuclei of one or more of the cells may migrate toward the base of the ommatidium, and often the cells themselves become arranged in two layers, some-

times with one cell at the base of the ommatidium and the other seven distal, sometimes with three in a basal layer and four in a distal layer. As already noted, the primitive number of retinula cells appears to be eight; but one is commonly reduced in size and separated from the rhabdom, leaving only seven taking part in the formation of the latter (fig. 32 D), and in such cases, if one of these becomes basal, only six appear in cross-sections through the distal part of the retinula.

The ommatidia are usually separated from one another by cells containing a dark pigment. When this pigment extends through the entire depth of the eye, it serves to isolate optically the individual ommatidia, and to make each a separate receptive element of the eye. The effect of light entering an eye thus divided into isolated tubes must be to give a mosaic image of the exterior, and this is regarded as the usual form of vision with diurnal insects. In the eyes of some nocturnal species, however, it is said that on the decrease of light the pigment condenses between the outer parts of the ommatidia, allowing light rays from any one point to spread over the retinulæ of several ommatidia, thus giving a more effective vision in dim illuminations. Usually but one set of pigment cells is described, besides the corneal pigment cells, but in some eyes there are two sets, a distal one and a proximal one. The distal pigment cells invest the cone and the corneal cells and are conveniently distinguished as the *iris pigment cells* (fig. 32 A, B, C, *IPgCl*). The proximal pigment cells surround and separate the retinulæ and are usually known as the *retinal pigment cells* (A, B, D, *RPgCl*), though they may also embrace the base of the cone. The number of pigment cells of both sets varies much in the eyes of different species of insects. There is some confusion in the names applied by writers to the several sets of pigment cells in the compound eye, including the pigmented corneal cells, due in part to the lack of uniformity in the cells themselves, and in part to the fact that it has not always been recognized by reviewers that the corneagenous cells are the pigment cells immediately investing the cone, except when they retain their primitive subcuticular position.

Compound eyes divided into two parts are common in several orders of insects, and frequently the two parts differ in the internal structure of the ommatidia, probably in accommodation to different ranges of vision or different intensities of light.

THE OCELLI

The various forms of simple eyes of insects have probably been developed independently of one another, and none of them has been

proved to have any developmental relation to the compound eyes. Those of most primitive structure occur in the larvæ of the Dipteran families Chironomidæ and Culicidæ, while the ocelli of the Ephemeridæ are perhaps the most highly evolved type. These facts and others indicate that the structure and comparative complexity of the ocelli have no phylogenetic significance, and suggest that ocelli are not the primitive visual organs of insects, but are secondarily acquired organs supplemental to the compound eyes, or substituting for them where the latter have been suppressed.

The ocelli are characterized by their individuality, but they cannot be defined on the basis of a type structure, because they differ so much among one another and have in general no feature that may not be found in ommatidia of compound eyes. They may occur in groups, though a group does not function as a single organ, but a compound eye, as already noted, may degenerate into detached ommatidia. The following six types of simple eyes are to be distinguished:

1. The lateral ocelli of Chironomid and Culicid larvæ.

2. The median ocellus of Collembola.

3. The lateral ocelli of larvæ of insects having a pupal stage, except the eyed larvæ of Diptera and Hymenoptera.

4. The frontal or dorsal ocelli of adult insects and of the young of insects having no pupal stage, except Collembola and Ephemerida, and the lateral eyes of adult fleas.

5. The frontal ocelli of Ephemerida.

6. The lateral ocelli of Tenthredinoidea.

The ocelli of Chironomid and Culicid larvæ are the simplest of all insect eyes and have a striking similarity of structure to the eyes of the Turbellarian worm, *Planaria*. There are two on each side of the head, each eye consisting of a few simple sense cells lying beneath a clear area of the cuticula, with their distal ends in a pigmented cup of the hypodermis. The pigment probably serves to limit the direction of the light rays that may fall upon the sense cells.

A median frontal ocellus similar in structure to that of Dipteran larvæ has been noted in a few species of Collembola. That of *Orchesella* is somewhat more highly evolved than the Dipteran larval eye, and its sense cells have rhabdomere 'borders. These two groups of insects are so widely separated, however, that it does not seem likely there can be any genetic relationship between the eyes of one and those of the other.

The lateral ocelli of Neuropteran, Coleopteran, and Lepidopteran larvæ consist of an invagination of the hypodermis beneath a lenti-

cular thickening of the cuticula, with the sense cells differentiated at the inner end of the cup and a crystalline body formed as a secretion in the distal part beneath the lens. These eyes occur in a group on each side of the larval head, frequently at the place where the compound eye is to be developed in the pupa, but it has been shown that the larval eyes degenerate without taking any part in the formation of the compound eye, and there appears to be no ground for the idea that the larval ocelli are ommatidia of the adult eye. So far as known to the writer, the roots of the ocellar nerves have not been traced in the larval brain, and until this is done the status of the ocelli probably cannot be decided. In a caterpillar the ocellar nerve trunks arise from the lower parts of the lateral brain lobes, immediately lateral to the antennal nerves, and follow a long semicircular course forward and outward to the ocelli. The optic lobes of the adult are developed from tissues within the larval brain.

The typical frontal or dorsal ocelli of adult insects are without doubt the primitive ocelli of insects since they occur in all the principal orders except the Collembola and Ephemerida. In these ocelli the hypodermal elements become arranged in two horizontal layers, usually by a process of delamination of the cells where the eye is formed. The cells of the outer layer are the corneagenous cells. Generally they secrete a thick biconvex cuticular lens and then become reduced to a thin transparent sheet over the inner layer. The latter consists of the retina cells which become grouped into rhabdom-forming retinulæ. Typically, there are three frontal ocelli, one median and two placed more laterally, but there is evidence in the structure and development of the median eye that it is the product of the fusion of an original pair of eyes. Sometimes the median ocellus is lacking where the others persist. The lateral simple eyes of adult fleas show by their structure that they are ocelli of the frontal type; probably they are the paired frontal ocelli that have moved to the sides of the head in the absence of compound eyes.

The frontal ocelli of adult Ephemeridæ are in certain respects similar to the frontal ocelli of other insects, but they differ from all other insect eyes in having a multicellular hypodermal lens formed apparently by an invagination of the outer surface of the eye.

The large, single, lateral ocellus of the larvæ of sawflies (Tenthredinoidea), finally, is somewhat of an anomaly among insect eyes. In structure it resembles the frontal ocelli of adult insects, but these are eyes that no other larva possesses. On the other hand, it has certain characters that have suggested the idea that it is a prototype of the compound eye, a claim disproved, however, by other in-

vestigators. Certainly it has no relation to the lateral eyes of other larvæ, and must be regarded, therefore, either as a primary frontal ocellus persisting in a larval stage and moved to the side of the head, or as an independent development.

POSTSCRIPT

Much has been omitted from the foregoing accounts of the structure of the sense organs and the nervous system of insects that a complete discussion of the subjects involved should contain, though the writer hopes that no recorded information has been overlooked or withheld that would weaken the general statements given, or that might have an important bearing on the matters discussed. Many of our present ideas on insect morphology are still in a controversial stage, and undoubtedly some current generalizations will be found to be based on a too limited knowledge of the facts, considering the great diversity in all the structural parts of insects. The writer, however, who undertakes to present a review of the facts known in any branch of insect anatomy must remember that his offering will be of value chiefly to the student or to the practical entomologist looking for concise information, and who is likely not to be interested in long discussions on subjects still under dispute among specialists.

On the other hand, a reviewer, through his desire to have his subject matter well classified, or to make it appear as complete as possible, may err in presenting it in a form more concise and more definite than is warranted by the facts. This is exemplified in the treatment of insect sense organs as commonly given in entomological texts, where each known group of organs is assigned to a special sense, as is done in text books on human anatomy, while from the writings of specialists it would appear that almost nothing is settled concerning the functions of the insect organs. The condition, however, is not one of chaos. The last twenty-five years has seen a vast increase in our knowledge of insect structure in general, and in particular of the sense organs, but by this very increase of printed information the work of assembling and reviewing it has become a task that can scarcely be done except by one who has all his time to devote to it. We must note with satisfaction, however, the increasing importance being given to morphology by the authors of our present general texts on entomology, and it is clear that the painstaking work of recent students will give to the subject of insect anatomy in the future a higher scientific standing than its adherents have heretofore been able justly to claim in its behalf.

ABBREVIATIONS USED ON THE FIGURES

AB, apical body.
ACy, association cyton.
Alv, alveolus.
AntNv, antennal nerve.
aTm, anterior tympanum.
aTr, anterior trachea.
Axn, axon, or neurite.

BC, body cavity (of leg).
BM, basement membrane.
1Br, protocerebrum.
2Br, deutocerebrum.
3Br, tritocerebrum.
BW, body wall.

CCl, cap cell.
Cl, cell.
Cn, crystalline cone.
CnCl, cone cell.
CœCom, circomœsophageal commissure.
Col, collateral.
1Com, protocerebral commissure.
2Com, deutocerebral commissure.
3Com, tritocerebral commissure.
Cor, cornea.
CorCl, corneagenous cell, or corneal pigment cell.
Cr, crest.
Ct, cuticula.
Cy, cyton (cell body).
CyI, sensory cell of Type I
CyII, sensory cell of Type II.

d, distal process of sense cell.
Dct, duct.
Dm, dermis, endocuticula.
Do, dome.

ECl, enveloping cell.
Ect, ectoderm.
Epd, epidermis, exocuticula.
EW, wall of tympanal cavity.

FrCom, frontal commissure.
FrGng, frontal ganglion.
FrNv, frontal nerve.
Fas, fasciculus of sense cell processes.

GGng, gastric ganglion.
4Gng, fourth head ganglion (mandibular).
5Gng, fifth head ganglion (maxillary).
6Gng, sixth head ganglion (labial).
7Gng, first thoracic ganglion.
GngCls, ganglion cells.

Hr, hair, seta.
HrCl, trichogenous cell.
HrMb, articular membrane of hair.
Hy, hypodermis.

ImO, intermediate organ.
IPgCl, iris pigment cell.
IT, first abdominal tergum.

LbNv, labial nerve.
LCom, longitudinal commissure.
LGng, lateral stomatogastric ganglion.
LmNv, labral nerve.
LW, leg wall.

Mb, membrane.
MbCl, cell of hair membrane.
Mcl, muscle.
MCy, motor cyton.
MdNv, mandibular nerve.
MxNv, maxillary nerve.

Nbl, neuroblast.
NlG, neural groove.
Nlm, neurilemma.
NlR, neural ridge.
Nu, nucleus.
Nv, nerve.

Œ, œsophagus.
ŒGng, œsophageal ganglion.
ONv, ocellar nerve.
OpL, optic lobe.

p, proximal process of sense cell.
Pi, pit.
Pl, sensory plate.
pTm, posterior tympanum.
pTr, posterior trachea.

r, ribs of sense rod.
Ret, retinula cell.
Rhb, rhabdom.
RNv, recurrent nerve.
RPgCl, retinal pigment cell.

SB, sensory body.
SCl, sense cell.
SCls, sense cells.
SCy, sensory cyton.
1Seg, first segment of antenna.
2Seg, second segment of antenna (pedicel).
3Seg, third segment of antenna.
SgNv, subgenual nerve.
SgO, subgenual organ.
SNv, sensory nerve.
SœGng, subœsophageal ganglion.

Sp, spiracle.
SPg, sensory peg.
SpGng, spinal ganglion.
SR, sense rod (scolopala).
SRs, sense rods.

t, terminal filament of sense rod.
TC, tympanal cavity.
Tm, tympanum.
TmNv, tympanal nerve.
TmO, tympanal organ.
Tnd, tendon.
TndCl, tendon-forming cell.
Tr, trachea.
TS, terminal strand.
Tu, tubercle.

Vac, vacuole.

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FOSSIL FOOTPRINTS FROM THE GRAND CANYON

(WITH TWELVE PLATES)

BY
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United States National Museum

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With 12 Plates

INTRODUCTION

Tracks of extinct quadrupeds were first discovered in the Grand Canyon in 1915 by Prof. Charles Schuchert, and specimens collected by him at that time were made the basis of a short paper by Dr. R. S. Lull [1] in which were described two species, *Laoporus schucherti* and *L. nobeli,* from the Coconino sandstone.

In the summer of 1924, the locality was visited by Dr. John C. Merriam, president of the Carnegie Institution of Washington, who made a small collection of tracks which were later presented to the United States National Museum. While at the locality, Doctor Merriam conceived the idea of having a permanent exhibit of these footprints *in situ* on the Hermit Trail, to teach a lesson as to the great antiquity of the animal life that once roamed over these ancient sands—a lesson that could not fail to be understood by the veriest tyro in geological phenomena. This plan was presented to Hon. Stephen F. Mather, director of the National Park Service, who immediately became interested in the project, and, with the aid of friends of the Park Service, arrangements were perfected whereby, in the late fall of 1924, the writer was detailed to visit the locality and prepare such an exhibit, and at the same time to make a collection of the footprints for the United States National Museum. Both of these undertakings were successfully carried out.

The collection made for the Museum, consisting of a series of slabs some 1,700 pounds in weight and carrying a great variety of excellently preserved imprints, is of more than usual interest, especially in coming from a locality and formation in which but the two species of Ichnites mentioned above have been recognized previously. Even with the diversity of forms now secured, it is quite

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[1] Amer. Journ. Sci., Ser. 4, Vol. 45, May, 1918, pp. 337-346, pls. 1-3.

apparent that all varieties to be found at this locality are not represented. It is upon this collection and the one made by Doctor Merriam earlier in the year that the present study is based.

FIELD EXHIBIT OF FOSSIL FOOTPRINTS

A preliminary survey of the locality on the Hermit Trail showed that the natural conditions were most favorable for the preparation of an exhibit of the tracks *in situ*. The rather steep slope of the cross-bedded sandstone on whose surface the tracks are impressed stands at an inclination of nearly 30 degrees facing toward the Trail, over which, in the course of a year, hundreds of tourists travel on mule back in making their pilgrimage to the bottom of the canyon. Furthermore, it was found that the upper superimposed layers or laminæ scaled off in large sheets, thus uncovering the tracks and trails beneath. The preparation of this exhibit required first the removal of the overburden of loose dirt and broken rock down to the more compact layers, and then the quarrying off of the loose upper laminæ until a solid and continuous face covered with footprints was reached. In this way a smooth surface 8 feet wide and 25 feet long was uncovered, as shown in plate 1, figure 1. The upper surface of this large slab has a great many tracks and trails leading up the slope, a few passing over and under the more or less horizontal strata shown at the top. At the side of the slab and leading up from the trail a flight of stone steps was laid in order to facilitate examination by those interested in a closer inspection of the footprints. At the base of this main exhibit, other large slabs lying close to the trail were similarly cleared off (see pl. 1, fig. 2), so that there are now several hundred square feet of rock surface forming a permanent exhibit of the various tracks and trails that are to be found here.

The great antiquity of these footprints, which occur from 900 to 1,080 feet below the level of the present rim of the canyon, is clearly demonstrated at this locality. It is obvious that since the day when those animals impressed their feet in what at that time was moist sand, more than 1,000 feet of rock-making materials were piled up in successive strata above them, and this does not take into account many hundreds of feet more that have been eroded off from the present top of the canyon wall. The great length of time required for the cutting away or erosion of the rock to form the deep canyon, and the even longer time necessary for the original deposition of this great vertical mass of stone is, when translated into terms of

years, if that were possible, so stupendous as to be almost beyond human comprehension.

It is hoped that the object lesson so graphically taught by this unique exhibit may serve as an example to stimulate the preparation and preservation of other natural phenomena to be found in our government-controlled parks, monuments, and reservations.

GEOLOGICAL OCCURRENCE

The Coconino sandstone of the Hermit Trail in which these tracks occur is considered Permian in age.[1] In this section it has a total thickness of 350 feet, but, so far as known, footprints are found only in the lower half. The greater part of the material here described was collected from one level about 150 feet above the base of the formation (see fig. 1). A few tracks were found at a level of 20 feet above the base, the lowest point at which imprints appeared. Between these two extremes, tracks were observed at several levels, and there is reason for believing that they may prevail continuously throughout the lower part of the sandstone. At the 150 foot level, tracks were traced laterally for a distance of 700 to 800 feet.

The Coconino sandstone is described by Noble as follows:[2]

The Coconino sandstone is a pale-buff fine-grained cross-bedded sandstone whose distinctive features are its massive appearance, the huge scale of the cross-bedding, and the uniform fineness of the component grains of sand. The massiveness of the sandstone, which is due to the coarseness of the cross-bedding, causes it to weather into the highest and most precipitous cliff in the upper wall of the canyon.

The formation is made up of lenticular beds, each of which is truncated by the bed above it in such a way that, as outlined in cross section or cliff faces, the beds commonly form irregular wedges whose sides are sweeping curves. Each wedge consists of innumerable thin inclined laminæ. Horizontal bedding is absent except near the base of the formation, where it is inconspicuous. . . . The laminæ form parallel curves that flatten downward. Commonly at the top of a wedge they are inclined at angles of 15° to 25°, or exceptionally 30°, but near the base of a wedge they bend and become horizontal or nearly horizontal.

The fossil tracks occur on the upper surface of these inclined laminæ. In removing the laminæ it was found that the underlying surfaces were often devoid of tracks, while the very next layer might be thickly covered. Sometimes as many as four distinct kinds of tracks were found on one surface. Some slabs were literally covered with imprints and curiously enough all pointed in the same direc-

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[1] Noble, L. F., Prof. Paper 131, U. S. Geol. Surv., 1922, p. 26, pl. 19.
[2] *Op. cit.*, p. 66.

tion—up the steep slope of the sandstone layer, suggesting an old trail leading to the water, or possibly recording a great migration of animal life such as is occasionally known to take place among the animals of the present time. Of all the trails collected and the still greater number observed in the field, but one exception to the uphill movement was noted, this being the tracks of a large quadruped, which clearly pointed down the hill (see p. 30). In this connection it is interesting to quote from Sir William Jardine's *Ichnology of Annandale* (p. 5):

> It is a curious fact that nearly all the footprints are impressed as if the animal had walked from west to east or from where we presume water to have been toward the land.

No doubt tracks occur in the Coconino sandstone at many other localities, having been reported on the rocks near "Dripping Spring," also in the Hermit Basin, but the usual precipitous face of the formation, except in a few favorable places, does not permit searching for them.

Because of the many resemblances in structural and lithologic features to the De Chelly, Navajo, and Wingate sandstones, all of which Gregory[1] regards as most certainly comprised of dune deposits, Noble is of the opinion that the Coconino sandstone is essentially of æolian origin.

That the evidence afforded by footprints of extinct animals may, in the absence of other fossil criteria, be of value in the correlation of widely separated formations, seems to be indicated by the recognition of generically like, if not specifically similar, tracks found in the Coconino sandstone of the Grand Canyon
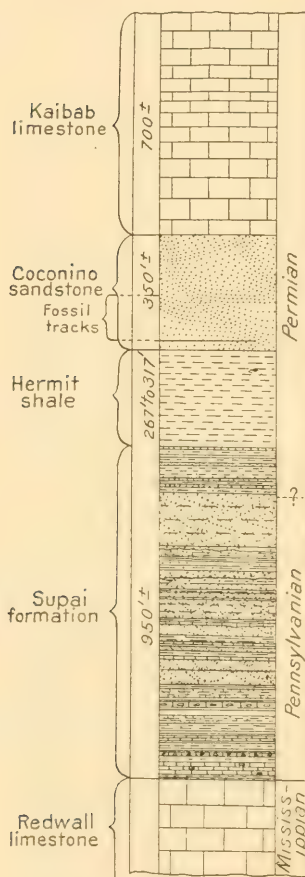
Fig. 1.—Upper part of the geological section at Hermit Trail. Position and extent of track-bearing strata indicated. Section (modified) after Noble.

[1] Gregory, H. E., Prof. Paper 93, U. S. Geol. Surv., 1917, pp. 31-34, 53-55, 57-59.

and in the Lyons sandstone of Colorado. The latter is regarded by Henderson [1] as late Pennsylvanian, but Willis T. Lee, in an unpublished manuscript, reaches the conclusion that the sandstones carrying the footprints in Colorado are Permian, which would seem to be more nearly in accord with the evidence furnished by the fossil tracks. Doctor Lee, in a letter under date of June 18, 1925, has kindly furnished the following statement in advance of the publication of his paper:

In this manuscript it is shown that the rocks formerly called Lyons include representatives of two distinct formations, one of Pennsylvanian age and one of Permian age and that the name Lyons sandstone is now restricted by the U. S. Geological Survey to the cross-bedded sandstone near Lyons, Colorado, which has been quarried extensively—that is, to the upper 100 feet of the rocks formerly called Lyons. The upper sandstone was found to overlap older formations and to be closely associated with rocks containing invertebrates believed to be of Permian age. These invertebrates are found in many places in limestone stratigraphically above the Lyons sandstone—that is, in the lower part of the Lykins formation. The Lyons sandstone as restricted is structurally more closely associated with the Lykins formation of probable Permian age than with the underlying Ingleside formation, of Pennsylvanian age, and is therefore regarded as Permian.

SYSTEMATIC DESCRIPTION OF GENERA AND SPECIES

The best preserved and most characteristic of the fossil footprints collected from the Hermit Trail are described in the following pages. The list of described forms might have been lengthened had it seemed wise to include all of the various kinds of imprints found, but in several instances the evidence was so meager as to deter one from the adoption of such a course. The possibility of acquiring still further material from this locality in the immediate future made it injudicious to describe tracks of which only a few imprints are known.

This study has resulted in the founding of a considerable number of new genera and species representing the only adequate Permian Ichnite fauna known from North America. Its chief value, however, is in recording a fauna which, as previously stated, may, in the absence of other fossil criteria, be of value in geological correlation. It has not been possible to place, with assurance, more than one or two of these newly described forms in a definite class. In a few instances suggestions are made as to the animal to which certain of the tracks may be attributed, but there now seems no possibility of definitely connecting them. Should there eventually be found a way of uniting the two lines of evidence, it is hoped that these tracks

[1] Henderson, Junius, Journ. Geol., Vol. 32, No. 3, 1924, p. 227.

may aid in bringing about a better understanding and interpretation of the habits and characteristics of the animals that made them.

Genus DOLICHOPODUS, new genus

Generic characters.—Quadrupedal. Pes long and narrow. Fourth digit long, slender, and curved outward. Three (?) toes in manus, which is placed behind and outside tracks of the pes. Toes acuminate, clawed, fifth digit of pes wanting. Feet turned strongly inward toward line of movement.

DOLICHOPODUS TETRADACTYLUS, new species

Plate 4, fig. 1

Type.—Catalogue number 11,123, U. S. N. M. A slab carrying a consecutive series of eight footprints.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (150 feet above base), Permian.

Description.—Stride about 230 mm.; width of trackway, 51 mm. *Hindfoot:* Four digits, fifth wanting, fourth long, slender, curved outward. Three inner digits progressively shortened. All toes acuminate except possibly the first. Heel rounded. Length of track 32 mm., width 15 mm. Length of digit I, 4 mm.; digit II, 5 mm.; digit III, 7 mm.; digit IV, 16 mm. *Forefoot:* Three (?) parallel digits, toes acuminate. Placed behind and outside hind foot.

The selected type of this species is a consecutive series of eight footprints divided equally between the fore- and hindfeet of the right and left sides of an animal walking in a straight course. The imprints made by the forefeet are so indistinct as to be visible only by special lighting, and this, combined with the narrow trackway and length of stride at first gave the impression that the track was made by a bipedal animal. These front impressions fall behind and outside of the deeper imprints of the hindfeet, and in an oblique light three short parallel digits are clearly discernible, the outer two being of equal length and sharply pointed. The inner toe is much shortened. The toes of both feet are directed strongly inward toward the median line of the trackway.

The striking feature of the more deeply impressed tracks of the hindfeet, which, by the way, are quite unlike any others yet found at this locality, is the presence of a long, slender fourth digit terminated by a sharp claw that curves outward. On the inner side

of this long toe distinct impressions of three digits which become progressively shortened toward the inner posterior side of the foot are to be noted in two of the tracks. The second and third toes are sharply pointed with a tendency to turn outward as does the fourth. The termination of the short first toe is imperfect but it seems to have a rounded end. It is strongly divergent and is directed straight inward at a right angle to the long axis of the foot. There is no evidence of a fifth digit, but if present it would certainly have been registered be· cause of the depth of the foot impressions as a whole. All of the toes with the exception of the first of the hindfoot are directed forward in line of the course of movement.

The unusual feature of the tracks of the hindfeet being strongly in advance of those of the forefeet, the reverse of the usual condition, raises the question of their proper identification. The reasons for considering the deeply impressed tracks as having been made by the hindfeet are their larger size, narrower trackway, and deeper impression, for otherwise the weight of the body must have rested chiefly on the forefeet—an unreasonable supposition.

The impressions of the forefeet offer but little opportunity for comparison with described forms, but those of the hindfeet bear certain resemblances to the tracks

Fig. 2.—*Dolichopodus tetradactylus.* Type, No. 11,123. U. S. N. M. Diagram of series of footprints. About ½ natural size.

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of *Dromopus agilis* Marsh, such as the long, curved fourth digit with curved claw, as shown in figure 3. The absence of a fifth toe on the outside of the foot, the reversed curvature of the digits, and the hindfoot impression behind the fore show, however, that the two sets of tracks were made by quite different animals.

The footprints of *Dolichopodus tetradactylus* appear to have been made by an active animal with long hind limbs and a comparatively light body. That this creature carried the greater part of its weight almost entirely upon the hind limbs seems to be shown by the great depth of the imprints made by the hindfeet.
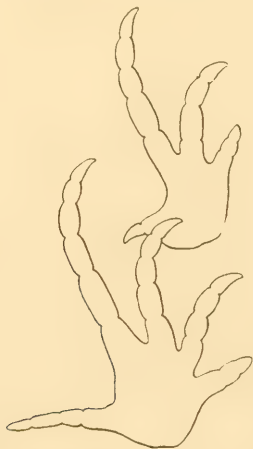
Fig. 3.—*Dromopus agilis* Marsh. Diagram of left fore and hind footprints. ½ natural size. (After Marsh.)

A survey of the known vertebrate fauna of the Permian discloses only one form, *Araeoscelis,* which, in its structure, is suggestive of a type of animal that might make a trackway similar to the footprints under consideration. Perusal of Williston's osteological description shows that a complete pes of this animal is unknown, but the restoration (see fig. 4) shows a fifth digit. In commenting on the number of digits Williston says:[1]

Only four metatarsals are preserved together in any one specimen, though the presence of the first tarsal would seem definitely to indicate the presence of the full five.

It would seem, therefore, that *Araeoscelis* must be ruled out of consideration as the maker of these tracks. On the other hand, the lack of evidence of a fifth toe in the tracks may be due to its failure to

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[1] Williston, S. W., Journ. Geol., Vol. 22, 1914, p. 390.

impress, but the depth of the hindfoot impressions as a whole leads to the conclusion that this digit was probably absent. An important distinction is thus furnished also between *Dolichopodus* and *Dromopus* which in many other features closely approach each other. If correctly restored the feet of *Araeoscelis* fulfil nearly all requirements for their correlation with the footprints called *Dromopus agilis* by Marsh.
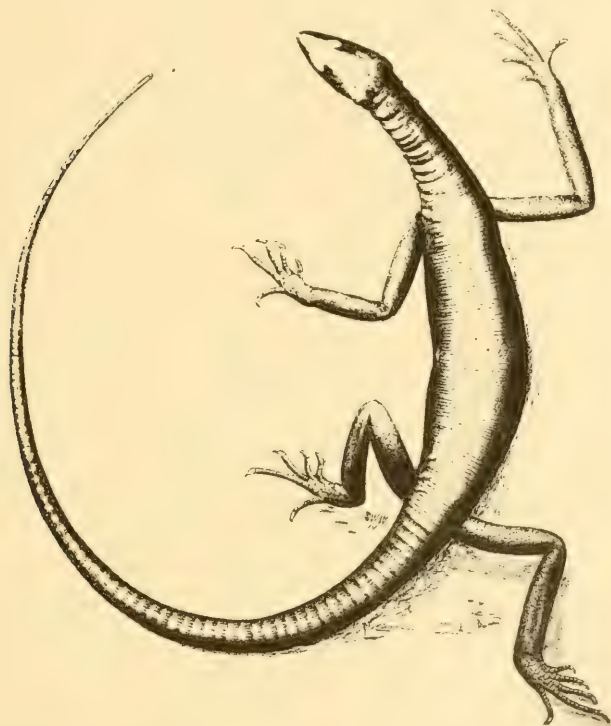
Fig. 4.—Restoration of *Araeoscelis*. An animal whose foot, limb, and body structure suggests the type of creature that made the tracks of *Dolichopodus*. About ¼ natural size. (After Williston.)

Resemblances in the general plan of the footprints here described to the feet of *Araeoscelis* leave but little doubt of their reptilian origin.

NANOPUS MERRIAMI, new species

Plate 4, fig. 2

Type.—Catalogue number 11,146, U. S. N. M. One slab (obverse) on which there is a consecutive series of tracks about 450 millimeters in length.

Type locality.—Hermit Basin, Hermit Trail, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (about 20 feet above the base), Permian.

Description.—Stride 62 mm., width of trackway, 50 mm. *Hind-foot:* Length 15 mm., width 12.7 mm.; four toes, the inner slender, sharp, and closely parallel to the second, the two median toes parallel

Fig. 5.—*Nanopus merriami.* Type, No. 11,146, U. S. N. M. Diagram of series of footprints. About ½ natural size.

and directed straight forward, tips acuminate, clawed. Outer toe shortened and well set off from the third. Sole suboval, weakly impressed, nearly as long as the toes. Length of digit I, 5 mm.; digit II, 7.5 mm.; digit III, 7.2 mm.; digit IV, 4.5 mm. *Forefoot:* Length about 11 mm., width 9.5 mm; three toes, outer slightly divergent, inner and outer digits shorter than median and subequal in length. Sole small, suboval, weakly impressed. Toes appear to bear slender, pointed claws. Length of digit I, 4.5 mm.; digit II, 6 mm.; digit III, 4.6 mm. The weight of the animal, judging from the depth of the

imprints of the feet, must have been about equally distributed between the fore and hind limbs.

The series of tracks selected as the type of the new species *Nanopus merriami* are of especial interest from the fact that they mark the lowest horizon in the Coconino sandstone where fossil footprints were found *in situ*. This level is about 20 feet above the base of the Coconino sandstone, or about 1,080 feet below the rim of the canyon. Only the obverse of the foot impressions was secured (see pl. 4, fig. 2), but a plaster cast shows the imprints as clearly as they were on the original rock surface.

The presence of three and four digits respectively on the manus and pes; parallel grouping of the two middle toes of the hindfoot, which are subequal in length; forefoot placed in front of the

Fig. 6.—*Nanopus caudatus* Marsh. Outline of left fore and hind footprints. Natural size. (After Marsh.)

hind; broadly rounded sole; and small size (see fig. 5) constitute a group of characters found in the genus *Nanopus*[1] from the Coal Measures of Kansas (fig. 6), a genus with which the present species seems to have its closest affinities. The genus *Barillopus* established by Matthew[2] upon footprints from the Coal Measures of Nova Scotia has a similar digital formula (see fig. 7) but the subequal length and parallel grouping of the three outer digits of the pes, the widely divergent toes of the manus, and the placing of the hindfoot upon the track of the fore, seem sufficient to show the distinctness of *Barillopus* from the footprints under consideration. The slenderness of the digits terminated with sharp claws in *Barillopus* are, however, more in accord with the present specimen than the heavy toes with rounded extremities without claws in the type of the genus *Nanopus*.

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[1] Marsh, O. C., Amer. Journ. Sci., Vol. 48, 1894, p. 82, pl. 2, fig. 1, pl. 3, fig. 1.
[2] Matthew, G. F., Canadian Rec. Sci., Vol. 9, No. 2, 1903, p. 103.

After careful consideration of the characters briefly reviewed above, the weight of evidence seems to favor the reference of the present specimen to the genus *Nanopus*. Three species have previously been described, *N. caudatus* Marsh, *N. obtusus* Matthew, and *N. quadratus* Matthew.

The specific distinctness of *Nanopus merriami* from *N. caudatus* is shown by the more slender form of the digits terminated by sharp claws, relatively shorter soles, smaller size, and lack of tail trace. The last mentioned feature is probably unimportant, for the dragging of the tail must often have depended on the occupation of the animal. The lack of claws, strongly divergent outer toe, unequal length of the two middle digits of the pes, heavier digits, quadrate form of

Fig. 7.—*Barillopus arctus* Matthew. *a*, Left hindfoot; *b*, left forefoot. About twice natural size. (After Matthew.)

the sole, and forefoot placed behind the hind, effectually distinguish the Canadian species from *Nanopus merriami*.

No tracks referable to this species were found in the higher track-bearing levels of the Coconino sandstone, but larger collections are necessary before one can be assured that they are confined to the lowermost part.

Marsh was of the opinion that *Nanopus caudatus* in all probability favored a reference to the Amphibia, but the nature of the animal indicated by the impressions of *N. merriami*, although a matter of conjecture, might with equal probability be considered reptilian.

The species is named for Dr. John C. Merriam, president of the Carnegie Institution of Washington, who was instrumental in bringing about the arrangements whereby this excellent series of footprints was acquired for the national collections.

Genus LAOPORUS Lull

The genus *Laoporus* is characterized by Lull as follows:

Generic characters.—Quadrupedal, without tail trace, with four digits in the manus and five in the pes, semiplantigrade, broad-soled, with short digits which in the impressions lack phalangeal pads. Traces of claws appear to be present but they have no grasping predatory function. Feet turned inward toward the line of march.

Footprints of the genus *Laoporus* are found more commonly than any other at the Hermit Trail locality. The large slab shown in plate 1, figure 1, has nearly one-half of its surface literally covered with these tracks, and a second slab (see pl. 1, fig. 2) is similarly decorated.

The closest affinities of *Laoporus* seem to be with *Limnopus* Marsh[1] (see fig. 8), and while the latter has a similar digital formula, the heavy, thickened toes with rounded extremities apparently lacking claws, the strongly divergent fifth digit, and the overlapping of the hindfoot impressions on those of the forefoot, seem sufficient to distinguish this genus from *Laoporus*.

Lull[2] comments on the character of the animals making the tracks ascribed to *Laoporus* as follows:

The creatures which made the footprints were quadrupeds of moderate size, with broad, stumpy feet, apparently clawed, and having at least four toes in front and five behind. The hindfoot, which is somewhat larger, bore a proportionately greater share of the creature's weight, especially in the smaller species [*L. schucherti*]. The limbs were apparently short, with a wide trackway, implying a bulky body. No trace of a dragging tail is discernible on any of the specimens, and the body was carried clear of the ground.

These observations apply equally well to the new materials discussed in the following pages. At this time I see no way of definitely determining whether the impressions are amphibian or reptilian in origin.

LAOPORUS NOBELI Lull

Plate 5, fig. 2; plate 6

Laoporus nobeli, Lull, Amer. Journ. Sci., Vol. 45, 1918, pp. 339-341, pl. 2, text fig. 2.

A beautifully preserved trackway (No. 11,148, U. S. N. M.) from a level 150 feet above the base of the Coconino sandstone (see pl. 5, fig. 2) is identified as pertaining to *Laoporus nobeli* Lull,

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[1] Marsh, O. C., Amer. Journ. Sci., Vol. 48, 1894, p. 82.
[2] Lull, R. S., Amer. Journ. Sci., Vol. 45, 1918, pp. 339-341.

and while none of the imprints have more than three toes registered, the close agreement in foot proportions, width of trackway, and length of stride all point to its affinities with the above mentioned genus and species.

As originally determined by Lull, *Laoporus* has four toes on the manus and five on the pes, this being fully substantiated by the paratype (No. 8422, U. S. N. M.) upon which the genus is partially based, and which has been of the greatest assistance in arriving at a proper identification of the recently acquired material. The shallowness of the prints on slab No. 11,148, U. S. National Museum, largely explains the absence of the missing toe impressions, and that there were other toes is evidenced by the lateral projection of the foot mass, entirely sufficient to have carried the proper number of additional digits.

Fig. 8.—*Limnopus vagus* Marsh. Outline of fore and hind footprints of left side. Natural size. (After Marsh.)

A second slab (No. 11,122, U. S. N. M.) from the same level has on its surface a considerable number of footprints (see pl. 6) which also seem to belong to this genus and species. While these do not form a well-defined trackway, the clearness of many of the imprints contributes to a much better understanding of the detailed structure of the feet than has hitherto been obtained. All of the better impressed tracks are slightly larger than those of the type and other specimens, as may be seen by reference to the table of comparative measurements (p. 16), but those of the forefoot are almost identical in all other features with the paratype.

A study of the paratype in combination with these new specimens gives such a different conception of the plan of the feet from those depicted by Lull as to require a new drawing which is shown in figure 9. The manus, as clearly shown in the paratype, has only four digits, but they are distinctly separated at their bases, with a short, slender first digit and a slightly longer but divergent fourth. Digits

two and three are parallel, subequal in length, and distinctly separated. The palm is narrow antero-posteriorly, with the heel strongly rounded off toward the external side. In all of these respects the new material is in perfect accord with the excellent impression of the forefoot of the paratype, as shown in figure 9A. This figure was made from a cast, the specimen showing the obverse side of the imprint only.

The digits of the pes, instead of being short and blunt as originally depicted, are relatively long and distinctly separated. Only one of the footprints on the slab numbered 11,122 shows any evidence of a fifth toe (see fig. 9C) and its presence in the other tracks of this genus and species would be unsuspected if it were not for the
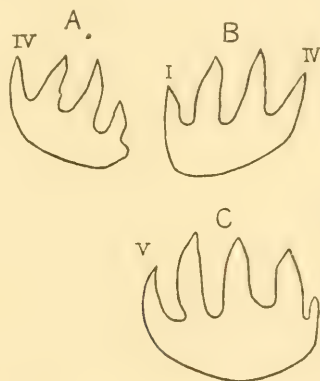
FIG. 9.—*Laoporus nobeli* Lull, *A*, Outline of left forefoot. Paratype, No. 8,422, U. S. N. M. *B, C,* Fore- (right) and hindfeet (left) of No. 11,122, U. S. N. M. All ¾ natural size.

claw drag showing five in the paratype. The evidence is conclusive in this respect, as first recognized by Lull, for where the creature dragged the hindfoot of the left side there are five distinct narrow scratches. The first toe, although relatively short, is distinct; the second, third, and fourth are of subequal length; the fifth is seldom plainly impressed. All are acuminate.

A critical examination of Lull's illustration of the type [1] specimen shows that the imprints are rather shallowly impressed and for that reason fail to give a true conception of the foot plan, especially as to the character of the digits. This will explain the great disparity existing between the original figures and the present conception (see fig. 9) based upon more abundant and better preserved specimens.

[1] *Loc. cit.,* pl. 2, fig. 1.

2

In addition to the specimens mentioned above, the collection contains numerous short series of tracks, none of which is worthy of special mention. In plate 9 is shown a trackway of *Laoporus nobeli* diagonally crossing that of *Baropezia eakini*.

COMPARATIVE MEASUREMENTS

	Type No. 2, 144 Yale Mus.	Paratype No. 8, 422 U. S. N. M.	No. 11, 148 U. S. N. M.	No. 11, 122 U. S. N. M.
MANUS	*mm.*	*mm.*	*mm.*	*mm.*
Length	20.0	20.2	19.0	21.0
Width	21.0	22.5	23.0	25.0
Length of digit I	....	6.0	3.0	8.5
Length of digit II	....	12.5	9.0	13.0
Length of digit III	....	10.0	9.0	11.5
Length of digit IV	....	6.5	....	8.8
PES				
Length	22.0	24.0	24.0	26.0
Width	31.0	28.5	28.0	32.5
Length of digit I	....	....	....	5.0
Length of digit II	....	....	6.0	12.0
Length of digit III	....	....	10.0	12.5
Length of digit IV	....	....	10.5	15.0
Length of digit V	....	....	....	....
Length of stride	112.0	119.0	105.0	....
Width of trackway	....	100.0	104.0	....

LAOPORUS COLORADOENSIS (Henderson)

Plate 7, figs. 1, 2

Limnopus (?) coloradoensis Henderson, Junius, Journ. Geol., Vol. 32, No. 3, 1924, p. 228, figs. 1, 2, 3.

Through the courtesy of Prof. Junius Henderson of the University of Colorado, the type and figured specimens of *Limnopus ? coloradoensis* (Nos. 13238, 14140 and 14141, Univ. of Colo.) from the Lyons sandstone (*Permian*), Lyons, Colorado, were loaned me for study and comparison with the footprints from the Grand Canyon.

In the original description this species was questionably referred to the genus *Limnopus* founded by Marsh[1] upon tracks from the Coal Measures of Kansas. (See fig. 8.) The presence of five distinct digits in the pes and four in the manus, with traces of claws,

[1] Marsh, O. C., Amer. Journ. Sci., Vol. 48, 1894, p. 82.

lack of phalangeal pads, broad soles and feet turned inward toward the line of movement, with forefoot placed in front of the hind, are all features indicating its affinities with the genus *Laoporus*. The dimensions of the imprints, width of trackway, and length of stride indicate its closest affinities to be with the smaller of the two described species, *L. schucherti* Lull, but the distinct separation of the fifth digit from the fourth of the pes, and the shorter length of digits one and four of the manus appear to show its distinctness from that species.

A rather indistinct trackway (No. 11,176, U. S. N. M.) collected by Dr. J. C. Merriam at the Hermit Trail locality shows a few hind-foot impressions that, except for their larger size, are indistinguishable from those of *Laoporus coloradoensis,* to which species they are referred. (See pl. 7, fig. 1, and compare A and B, fig. 10.)

More abundant specimens may show that *L. coloradoensis* and *L. schucherti* are synonymous, in which event, on the ground of
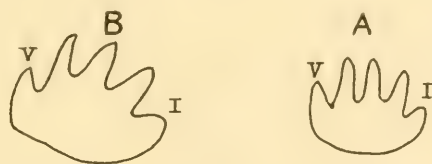
Fig. 10.—*Laoporus coloradoensis* (Henderson). *A,* Outline of left hind footprint. Type, No. 13,238, University of Colorado. *B,* No. 11,176, U. S. N. M. The same side. Both ¾ natural size.

priority, the specific name *coloradoensis* must be abandoned. For the present it seems best to retain both names, even though they cannot be adequately distinguished.

Upon examination of the two slabs of footprints (Nos. 14,140 and 14,141, Univ. of Colo.) illustrated by Henderson [1] I am quite assured that they have been properly referred to *L. coloradoensis*. Specimen No. 14,140 has quite a different arrangement of the tracks in that they form a continuous series not set off in pairs as in the type and other figured specimen. The width of trackway, however, agrees with the other two. The change of gait may have been brought about as Henderson suggests, by the animal creeping up a steep bank where travel was difficult. All details of the imprints on these two referred slabs are obscure. The foot structure is well shown in the accompanying figures, and their proportions are given in the table of measurements.

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[1] *Loc. cit.,* figs. 1 and 3.

COMPARATIVE MEASUREMENTS

	Type of L. schucherti	Type of L. coloradoensis	Specimen No. 11,176 U. S. N. M.
	mm.	mm.	mm.
Length of stride	73.8	85.0 [a]	109.0 [a]
Width of trackway...................	60.0	72.0	85.0
MANUS			
Width of impressions...............	16.8	16.8	19.0
Length of digit III	5.8	5.0	....
PES			
Width	21.0	20.0	27.0
Length to tip of digit III without claw.	18.2	14.5	18.7
Length of digit I	4.8	4.0	4.0
Length of digit II	7.3	5.5	8.0
Length of digit III	8.5	8.0	8.5
Length of digit IV	12.2	9.0	9.8
Length of digit V..	6.0	4.0	3.5
From tip to tip of outer digits........	16.00	17.0	24.0

[a] = average.

Genus **BAROPEZIA** Matthew

This genus was founded by Matthew[1] on specimens from the Coal Measures of Nova Scotia and included two species, *Baropezia sydnensis* (Dawson) and *B. abcissa* Matthew. Footprints from the Grand Canyon have a considerable resemblance to those of *B. sydnensis* in size, triangular form of the imprints of the pes, and smaller manus with short, heavy toes radially arranged, and I therefore tentatively refer the following new species to this genus.

BAROPEZIA EAKINI, new species

Plates 8 and 9

Type.—Catalogue number 11,137, U. S. N. M. Consists of a short consecutive series of deeply impressed tracks of which the obverse side is also preserved.

Paratype.—Catalogue number 11,138, U. S. N. M. Consists of a large slab of consecutive tracks that are less deeply impressed than the type.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

[1] Matthew, G. F., Proc. and Trans. Roy. Soc. Canada, 2d Ser., Vol. 10, 1904, p. 100.

Geological occurrence.—Coconino sandstone (150 feet above base), Permian.

Description.—Stride about 123 mm.; width of trackway about 144 mm. *Hindfoot:* Length 44 mm.; width 51 mm. Sole subtriangular, deeply impressed in type. There were five distinct subequal toes; digits short, with broadly rounded terminations without trace of claws, though there may have been a bluntly rounded nail. Fifth digit slightly divergent. *Forefoot:* Length about 28 mm.; width about 47 mm. Sole suboval, inside and front most deeply impressed. Five distinct radially arranged toes, and, as in the pes, short with
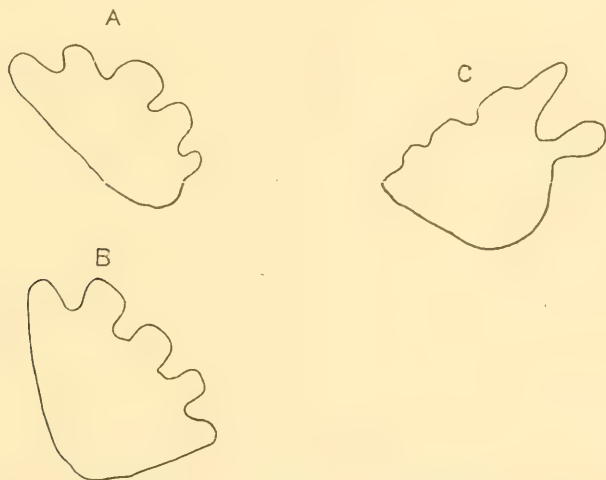
Fig. 11.—*Baropezia eakini.* Outline of footprints showing width of trackway and relative positions. Type, No. 11,137, U. S. N. M. *A*, Left forefoot; *B*, left hindfoot; *C*, right hindfoot showing deformed fourth and fifth digits. About ½ natural size.

bluntly rounded extremities, first much reduced, others apparently subequal in size; fourth and fifth divergent.

This species has the print of five toes on the hindfoot and apparently five on the fore. The tracks made by the hindfoot of the right side differ so from those of the left (compare fig. 11 and pl. 8) as to clearly indicate that the right has suffered injury causing two toes, the fourth and fifth, to protrude prominently outward from the side of the foot. This same peculiarity, though less distinctly indicated, is noted in the paratype (pl. 9) which leads to the conclusion that both series of tracks were made by the same individual. The paratype, a beautifully preserved trackway, is a striking example of the unreliability of the information to be obtained from fossil foot-

prints, even when the tracks seem to be fairly well impressed. Of more than 30 distinct tracks, none registers more than three toes, and were it not for the deformity of the toes of the right hindfoot, showing that the tracks of both type and paratype were made by the same animal, there might be some doubt as to their reference to the same species.

The digital formulæ of *B. sydnensis* and *B. abcissa* (figs. 12 and 13) as determined by Matthew, are 4-3 and 4-4 respectively. That

FIG. 12.—*Baropezia sydnensis* (Dawson). *A*, Mould of right forefoot; *B*, mould of right hindfoot. ½ natural size. (After Matthew.)

both may have additional toes which did not register seems quite probable, especially in the light of the two series of tracks discussed above. That Matthew was cognizant of such a possibility is indicated by his comment on the pes of *B. sydnensis* that " the first digit may be potentially present." Considered from the evidence furnished by this new material, it would seem quite certain that *B. sydnensis* has a formula of 5 and 4 digits instead of 4 and 3. There is also reason for thinking that Matthew may have been mistaken in his identification of the relative positions of the two tracks. In the narrowness, fore and aft, of the sole impression, the divergence of digit one, and in the relative size and arrangement of the other

digits, the imprint called *hindfoot* by Matthew certainly bears a closer resemblance to the track of the manus in *B. eakini* than to that of the pes. Furthermore, the subtriangular sole of the so-called
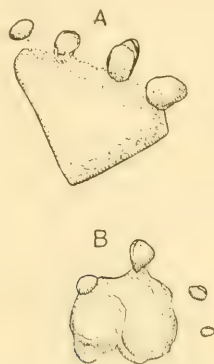
Fig. 13.—*Baropezia abcissa* Matthew. *A,* Mould of right hind-foot; *B,* mould of left forefoot. ½ natural size. (After Matthew.)

forefoot has its nearest counterpart in the pes of *B. eakini.* For these reasons it would appear that *B. sydnensis* also agrees with *B. eakini* in planting the forefoot in front of the hind instead of behind it as originally determined by Matthew.
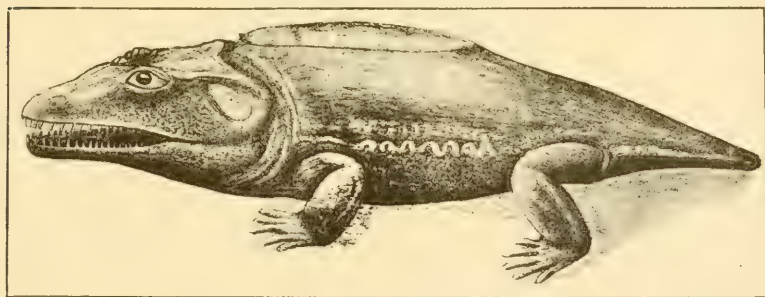
Fig. 14.—Restoration of *Cacops aspidephorus* Williston, a stego-cephalian amphibian from the Permian of Texas. (After Williston.)

The average distance between fore and hind tracks of the same side of *B. eakini* is about 16 millimeters. The feet turn in strongly toward the median line of the trackway. The front of the feet is always deepest impressed, probably because the animal was climbing a slope, an inference substantiated by the flow structure behind the tracks made by the material displaced by the feet. The toes of

both fore- and hindfeet are short and rounded without trace of claws, though they may have been terminated by blunt, rounded nails. In all, there are on the two slabs 45 tracks about equally divided among the four feet of the animal.

The creature making these tracks was apparently a short, squat quadruped with a wide body, and evidently slow of movement as indicated by the short stride. There is no evidence of a tail drag on

Fig. 15.—Restoration of *Trematops milleri* Williston. An amphibian from the Permian of Texas. (After Williston.)

either of the slabs. The forefoot impression is always placed in front and slightly outside the hind.

In reviewing the known Permian animals in search of the possible makers of these tracks, two forms were found, *Cacops aspidephorus* and *Trematops milleri*,[1] either of which appears to have the proper proportions to leave a trackway similar to the one under discussion, both being relatively short, wide bodied creatures with short, stubby tails and large five-toed feet without claws (see figs.

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[1] Williston, S. W., Journ. Geol., Vol. 22, 1914, pp. 61-62.

14, 15). Either of these animals would seem to fulfil all requirements in so far as the character of an animal can be visualized from a study of its tracks. The absence of a tail drag would also be accounted for by the presence of this short, stubby tail. According to Williston, *Cacops* has a length over all of about 20 inches, whereas *Trematops* is 36 inches long. If the above suggested correlation has any merit whatsoever, these tracks are at once placed as belonging to the stegocephalian branch of the Amphibia.

The specific name of *Baropezia eakini* is in honor of Mr. J. R. Eakin, superintendent of the Grand Canyon National Park, whose generous assistance contributed so much to the success in making this collection of fossil tracks.

Genus AGOSTOPUS, new genus

Generic characters.—Quadrupedal with five digits in the manus and four in the pes; plantigrade; broad soled with three clawed digits in the pes. Feet directed inward, hindfoot placed in front of forefoot impressions. Short limbed, wide bodied.

AGOSTOPUS MATHERI, new species

Plate 10

Type.—Catalogue number 11,135, U. S. N. M. Consists of a trackway some 700 millimeters in length, showing consecutive imprints of all the four feet.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (150 feet above the base), Permian.

Description.—Length of stride, 134 mm.; width of trackway, 199 mm. *Hindfoot:* Length about 67 mm., width 65 mm. Sole broad, palmate, quadrately rounded, longer than digits. Four digits, median two curved outward, outer three acuminate, probably terminated by sharp claws. First digit short, heavy, obtusely rounded, without claw. Length of digits, $I=4$ mm., $II=18$ mm., $III=22$ mm., $IV=18$ mm. *Forefoot:* Length (estimated) 35 mm., width about 63 mm. Sole suboval, smaller than hindfoot; apparently five short digits, fifth reduced and projecting outward at a right angle to the long axis of the foot.

In addition to the slab of footprints selected as the type, the collection contains two slabs (Nos. 11,133 and 11,150) pertaining to this species. The imprints, especially of the hindfeet, are clearly pre-

served, but the toes of the forefeet are usually cut off by the flow of sand crowded out by the heel of the hindfoot, thus destroying the evidence for a positive determination of the length of the toes of the manus.
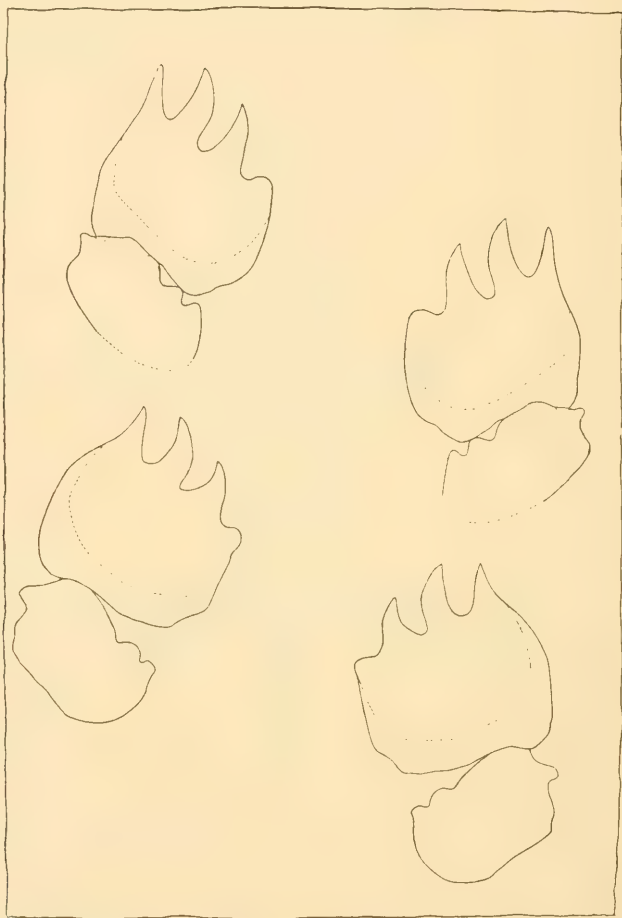
Fig. 16.—*Agostopus matheri.* Type, No. 11,135, U. S. N. M. Diagram of trackway. ⅓ natural size.

In the presence of four toes on the hindfoot and five on the fore, these tracks closely resemble *Megapezia pincoi*[1] from the Lower Carboniferous of Nova Scotia, but here their similarity practically ends, since they differ so much in size, length and arrangement of

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[1] Matthew, G. F., Proc. and Trans. Roy. Soc. Canada, 2d Ser., Vol. 10, 1904, pp. 102-104, pl. 2, figs. 4-4a.

the digits, and in the proportions and shape of the sole as to fully indicate their generic distinctness. It therefore becomes necessary to erect a new genus for their reception and the name *Agostopus matheri* is proposed. The specific name is for Hon. Stephen F. Mather, director of the National Park Service, whose personal interest was so largely responsible for the opportunity of making this important collection of fossil footprints.

The stride is comparatively short for so large an animal and the steps, as well as the width between the right and left rows, are remarkably uniform. The forefoot is placed behind and a little outside the line of tracks made by the hindfoot. The heel seems to be broadly rounded, as indicated by the broken line shown in figure 16. The heavier outer line of the pes tracks represents the outline of the disturbed sand which was pressed out by the impact of the foot. All of the tracks show distinct imprints of the soles, as may be seen in plate 10.

Inasmuch as the hindfoot is set partly on the toe marks of the antecedent impression of the forefoot, it resembles *Barillopus* Matthew, but its much larger size, sole longer than digits, different digital formula, and lack of tail mark at once distinguish it from that genus.

On the forefoot there are apparently five toes, all of which appear to be short. In arriving at the number of digits it was assumed that the divergent projection on the outside of the imprint represents a fifth toe. Such a protuberance is present in several of the tracks though there is a variation in shape and size, as indicated in figure 16.

Both fore- and hindfeet turn inward toward the center of the line of march. The creature making these tracks was evidently a short-legged, wide-bodied animal, apparently of sluggish habits.

Genus PALAEOPUS, new genus

Generic characters.—Quadrupedal, hindfoot somewhat the larger, always most deeply impressed. Five digits in pes, three or more in manus. Manus in direct line of pes tracks. Sole longer than toes. Broad, short toes without a trace of claws. Feet directed straight forward. Long limbed with regular stride.

PALAEOPUS REGULARIS, new species

Plate 5, fig. 1

Type.—Catalogue number 11,143, U. S. N. M. Slab containing a straight series of tracks of a single individual 1,200 millimeters in length.
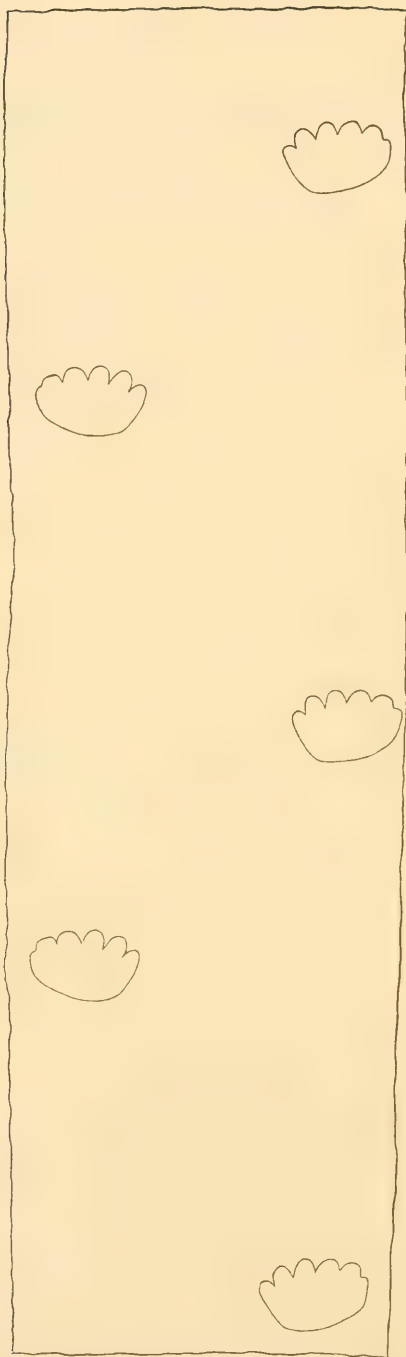
Fig. 17.—*Palaeopus regularis.* Type, No. 11,143, U. S. N. M. Diagram of trackway. ½ natural size.

Paratype.—Catalogue number 11,144, U. S. N. M. Obverse slab on which is a consecutive series of footprints 1,330 millimeters in length. The reverse of this series is a slab in the museum at the Grand Canyon National Park.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (about 150 feet above base), Permian.

Description.—Comparative measurements of the type and paratype show a fairly close agreement except in the length of stride, which is 152 millimeters in the type and 106 in the paratype, the width of trackway being 100 millimeters in both. *Hindfoot:* Length, 15 mm. in both type and paratype, width, 28.5 mm. in type, 25 mm. in paratype. Stumpy and larger than manus, and with five toes, short and without claws. Directed straight forward, often overlapping track of manus. *Forefoot:* Length of type, 11 mm., paratype, 10 mm.; width, type 20 mm., paratype 19.5 mm. Smaller and more shallowly impressed than pes, and with three ·(?) toes, short and without claws. Placed directly in line with hindfoot.

The trail made by this species is distinctive on account of the straight trackway and precise regularity of the imprints, especially those made by the hindfeet. The paratype was origi-

nally a slab 9 feet in length, the trackway extending the full length without the slightest deviation to the right or left.

The forefoot impressions are usually dimly impressed or absent. In many places on the type slab this is due to the hindfoot having been placed directly on top of the fore, thus obliterating the imprint. Often, however, only the posterior half is thus wiped out. In the paratype the hindfoot is shown falling in advance of the fore, evidently caused by a slower gait and slightly shorter stride. Judging from the relative depth of the impressions of the fore- and hindfeet, the greater part of the weight of the animal was borne by the latter. The ratio of foot length to length of stride is about 1 to 8.

The feet were broad and stumpy with digits largely buried in the mass of the foot. A few of the impressions made by the pes show five short, rounded toes (fig. 17). None of the forefoot impressions of the type gives any idea of the number of digits, but in the paratype a few are suggestive of the presence of at least three.

On the type slab (see pl. 5, fig. 1, reproduced from a photograph) a few shallow, half obliterated footprints of the manus may be seen immediately in advance of those of the pes; in the paratype the imprints of the manus fall behind those of the pes.

The creature making these tracks was evidently narrow-bodied, with long legs, and walked with an upright, mammalian-like stride. Such an arrangement of quadrupedal tracks could be accounted for only in this way. The straightness of the trackway and regularity of the stride at once distinguishes the trail of *Palaeopus regularis* from all others found at the locality.

Genus BARYPODUS, new genus

Generic characters.—Quadrupedal, with three digits in both manus and pes. Digits long, nearly parallel, well separated; appear to be joined by web. Sole subquadrate, longer than digits. Forefoot placed well forward of hind, both turned strongly inward.

BARYPODUS PALMATUS, new species

Plate 11, fig. 1

Type.—Catalogue number 11,134, U. S. N. M. Consists of a slab on which are single impressions of a fore- and hindfoot.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (150 feet above base), Permian.

Description.—Length of stride unknown. *Hindfoot:* Length, 115 mm., width, 87 mm.; sole palmate, longer than toes and longer than wide. Three toes, long, directed forward, and apparently without claws. Length of first digit, 37 mm.; second, 54 mm.; third, 38 mm. First digit slightly divergent, third protrudes slightly beyond the border of the web. *Forefoot:* Length, 108 mm., width, 58 mm. Outline of foot semi-rectangular with a distinct blunt, hook-like protuberance on inner posterior angle of heel. There seem to be three
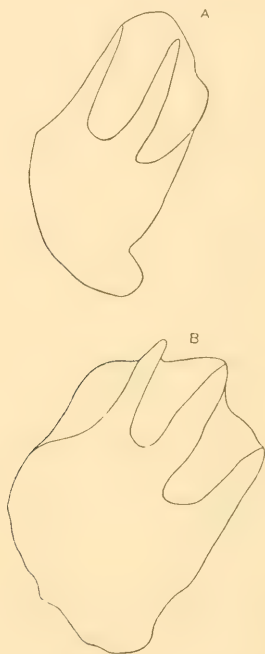
Fig. 18.—*Barypodus palmatus.* Type, No. 11,134, U. S. N. M. *A,* Diagram of forefoot; *B,* diagram of hindfoot. ⅓ natural size.

toes, the inner one being short, the outer two long, slender, and directed straight forward, all within the mass of the foot. The median toe, as in the pes, is most deeply impressed. Extremities of the toes show no trace of claws. Length of inner digit, 15 mm.; second, 52.5 mm.; third, 47 mm. At the base of the toes distinct cross ridges indicate the presence of creases. Forefoot 135 mm. in advance of the hindfoot impression.

Although the specimen selected as the type of this genus and species furnishes rather meager information concerning the tracks,

they are so distinct from the other footprints forming the collection from this locality that they seem worthy of description.

This form is remarkable for the large, heavy, semiquadrate soles and the apparent presence of web-like flanges that seem to extend between and beyond the tips of the toes. The presence of such a web is indicated in both manus and pes, but more especially the latter, by the depression of the sand between the toes and the numerous cross ridgings marking the surfaces. Its distinct outline is shown in figure 1, plate 11.

The large size of the animal making these tracks is indicated by the size of the footprints and depth of the impressions. Further material will be needed to elucidate the outlines of the feet, and it would not be at all surprising to find that there were additional toes. The web-like character of the feet is also found in the Triassic *Otozorum*[1] but this fact does not necessarily imply any relationship since the great size and different digital formula of the Mesozoic tracks at once distinguishes them. Although subequal in size with tracks here designated *Allopus ? arizonae,* those of *Barypodus palmatus* are at once distinguished by the long, slender, webbed toes, and by the lengthened quadrate form of the sole impressions.

A correlation of these tracks with any of the known Permian animals cannot be attempted without additional material, whereby the details of foot structure, length of stride, and width of body could be determined. The largest animals now known from the Permian are *Dimetrodon* and *Edaphosaurus,* either one of which may have been sufficiently large and heavy to make these tracks, but both have five well-developed digits, and it is hardly probable that either had webbed feet.

ALLOPUS? ARIZONAE, new species

Plate 11, fig. 2

Type.—Catalogue number 11,123, U. S. N. M. Consists of a consecutive series of footprints 8½ feet in length.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (150 feet above base), Permian.

Description.—Stride about 530 mm.; width of trackway about 330 mm. *Hindfoot:* Length about 60 mm., width about 85 mm. Apparently five toes which are very short with bluntly rounded ex-

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[1] Hitchcock, Edward, Ichnology of New England, 1858, p. 123, pl. 33, fig. 4.

tremities without claws. Third toe broadest. Two outer toes slightly diverted from three inner as in *Allopus littoralis* Marsh. Sole impressed but its posterior outline obscure; it appears to have been broadly rounded as in *Allopus*. Foot turned strongly inward toward the line of movement. *Forefoot:* Length (estimated) 45 mm., width about 72 mm. Two toes clearly recorded, but there may have been one or two more. Digital terminations especially broad and without claws. Sole appears to be broadly rounded behind. Footprint deeply impressed on the inside, angle of inclination inward toward the line of movement and less than the hindfoot.

The specimen selected as the type of this new species is the trackway of a quadruped and consists of eight pairs of footprints equally divided between the right and left sides. In size, length of stride,
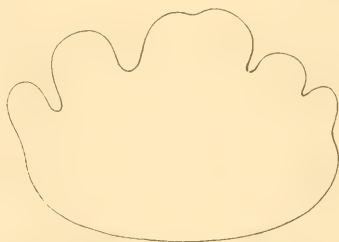
Fig. 19.—*Allopus? arizonae.* Type, No. 11,123, U. S N. M. Sketch of left hindfoot. About ½ natural size.

and toes with blunt, rounded extremities without claws, these show a marked resemblance to *Allopus littoralis* Marsh[1] from the Coal Measures of Kansas. I shall, therefore, tentatively refer these tracks to the genus *Allopus,* although there are differences which suggest that they probably pertain to a distinct genus.

The tracks are deeply impressed, but the sand was apparently so soft that the detailed foot plan was not recorded. Furthermore, the trail is crossed diagonally by the trackway of a second large animal, apparently of the same species, which in several instances stepped upon the footprints of the first, thus contributing still further to the difficulty of their proper interpretation. The last three pairs of the left side are the most distinct and the description is based almost entirely upon these six impressions of the fore- and hindfeet.

The consecutive series of tracks is unique from the fact that this was the only trackway found at this locality leading down the inclined slope; all others were ascending. For that reason there is

[1] Marsh, O. C., Amer. Journ. Sci., Vol. 48, 1894, p. 83, pl. 11, figs. 4, 4a.

some doubt as to the length of stride and the relative position of the imprints as representing the normal gait. For example, the imprint regarded as having been made by the manus falls behind and slightly inside the line of the larger impression made by the pes. In *Allopus littoralis,* as interpreted by Marsh, the positions are reversed.

The less number of digits on the manus and greater on the pes serves at once to distinguish this species from *A. littoralis* with its five and four respectively. However, until the detailed structure of the feet of this new form is more completely and positively known, it appears best to refer it to this established genus.

Marsh regarded the tracks of *Allopus* as having been made by a large labyrinthodont animal but the reduced number of digits in the manus does not suggest their assignment to any of those forms known from their skeletons.

As noted above, at the time this series of tracks was made the sand must have been thoroughly saturated with water as evidenced by the fact that it flowed back into the tracks from both sides, leaving a narrow longitudinal depression at the center where the flows failed to merge. Furthermore, on the down-hill side of the imprints, especially those made by the pes, the displaced sand has flowed downward for a distance of 200 to 225 millimeters. Three successive flows, one above the other, are registered, as indistinctly shown in figure 2, plate 11.

These features raise the question as to how an aeolian deposit of sand on a slope of 30 degrees could become so fully saturated with water. It could hardly be accounted for by submergence for under that condition the smaller tracks would hardly be registered so distinctly as many of them are. It permits of the suggestion that perhaps a further study of their origin, in the light of this new evidence, may bring about a modified conception of the æolian theory as accounting for the original deposition of these sandstones.

Genus PALEOHELCURA, new genus

Generic characters.—Foot apparently tridactylous; long axis of each cluster of three placed strongly diagonal to direction of movement. Tail trace.

PALEOHELCURA TRIDACTYLA, new species

Plate 12, fig. 1

Type.—Catalogue number 11,145, U. S. N. M. Consists of a slab about 560 mm. long, having a trail traversing the entire length.

3

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (a loose slab from hillside at a point about 125 feet above the base), Permian.

The trail here described consists of two parallel lines of tracks between which the drag of a caudal appendage is clearly registered. The lateral lines are formed by clusters of three imprints, evidently made by tridactyl, pointed extremities, the longer axis of which stands at about 45 degrees to the line of direction. The clusters al-
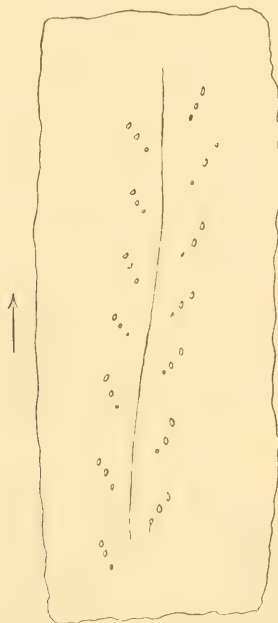
Fig. 20.—*Palaeohelcura triductyla.* Type, No. 11,145, U. S N. M. Diagram of trackway. Arrow indicates line of movement. ½ natural size.

ternate on the two sides. This alternating movement of the limbs of opposite sides is indicated in the undulating movement of the tail drag, which is quite clearly shown in plate 12, figure 1. The direction of movement is indicated by the drag of the toes as being in the direction shown by the arrow (fig. 20). The inner toe seems to be the smallest; the outer two are subequal in size. The greatest width of the trackway is 22 millimeters, length of stride about 17 millimeters, distance between single imprints of each cluster about 3 millimeters, and width of each cluster of three about 8.5 millimeters.

In looking at this specimen, one is struck by the general distinctness of the outlines and the perfection of preservation, but an attempt to refer it to a particular class of animals results in great perplexity. The wonder is that an animal, apparently so small and light, should have left any impression that could be converted into rock. It is quite unlike any of the described trails attributed to crustaceans, myriapods, or insects, and yet it gives every indication of having been made by some invertebrate animal. The specimen has been examined by the several specialists in the United States National Museum dealing with these groups, and all disclaim its relationship to any with which they are familiar.

Regardless of my inability to definitely classify these tracks, their distinctive character makes it desirable to name them, and the new genus and species *Paleohelcura tridactyla* is proposed for their reception. It is my impression that they represent the trail of some
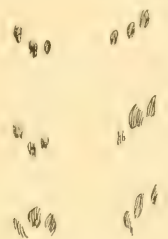
Fig. 21.—Undescribed trackway in museum at Weimar, Germany, from the Triassic. ½ natural size. Sketch by O. Abel.

invertebrate; they certainly do not display features indicative of the foot of any known vertebrate animal.

On a recent visit to the United States National Museum, the distinguished paleontologist, Prof. Othenio Abel, called my attention to a series of tracks preserved in the museum at Weimar which bear a certain resemblance to the tracks under consideration. These are shown in figure 21, reproduced from a sketch by Professor Abel who generously permitted its use. This series of tracks is from the Bundsandstein (Triassic) between Schonalkalden and Trowback near Nesselberg, and are therefore somewhat younger than the Grand Canyon specimen. They show the same grouping in threes set at an oblique angle to the median line of movement, and with a similar relative width of trackway. They differ, however, in their larger size, lack of tail trace, and in having the clusters of the two sides opposite, whereas the clusters alternate in the Arizona form. While these distinctions are important, the Austrian specimen is of interest in being

the only one known which bears any great resemblance to those here described.

A second slab (No. 11,141, U. S. N. M.) which was originally a part of that bearing the type, has on its surface a continuation of the *Palcohelcura* trail evidently made by the same individual. It differs from the type in having only a single toe mark on each side of the tail drag for one-half of its linear extent, the remaining half showing two imprints. In only three or four instances are all three toes registered. This serves to emphasize the necessity of securing abun-
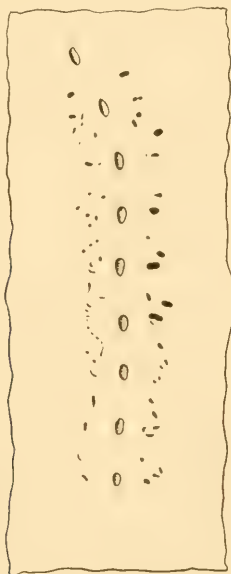
FIG. 22.—*Mesichnium benjamini.* Type, No. 11,155, U. S. N. M. Diagram of trackway. ½ natural size.

dant material for the study of fossil tracks if the chances of error are to be reduced to the minimum.

Genus MESICHNIUM, new genus

Generic characters.—Digital formula unknown. Row of regularly spaced oval depressions between the parallel lines of tracks.

MESICHNIUM BENJAMINI, new species

Plate 12, fig. 2

Type.—Catalogue number 11,155, U. S. N. M. Consists of a small slab on which is a trail about 300 millimeters in length.

Type locality.—Hermit Trail, Hermit Basin, Grand Canyon National Park, Arizona.

Geological occurrence.—Coconino sandstone (150 feet above base), Permian.

In plate 12, figure 2, is shown a photographic reproduction of two parallel lines of footprints which clearly represent the trail of some animal, but which, in most of its details, is quite obscure. The one distinctive feature is the presence of a median row of suboval depressions regularly spaced and for half the length of the trail deeply impressed; on the other half they are either shown faintly or missing entirely. The width of the trackway is 22.4 millimeters; distance between depressions of median row averages about 15 millimeters, which also represents the length of stride. Whether these median pits were formed by a caudal appendage or by a descending ventral protuberance on the body is of course impossible to determine. It would seem most logical to regard them as having been made by a short, stubby tail.

The direction of movement is shown on the forward border of the pits by the drag made by the appendage causing the oval depressions, as contrasted with the more perpendicular posterior side of the imprint.

The trail is quite different from any other in the collection, and I find nothing like it described. That it was made by some invertebrate there is little doubt, but no clue has been found as to the particular animal.

The specific name is in honor of Dr. Marcus Benjamin, who for many years has so ably edited the scientific publications of the United States National Museum.

SUMMARY

That both vertebrate and invertebrate animals are present in this collection of footprints is certain, but with the exception of the classes Reptilia and Amphibia among the former, quite certainly represented by the tracks designated *Dolichopodus tetradactylus* and *Baropezia eakini* respectively, it was found impossible to assign the other forms to their proper class with any degree of assurance.

No skeletal remains are known from the Coconino sandstone and consequently no direct clue is offered as to the makers of any of these tracks. A study was made of the Permian vertebrate fauna found in the adjacent regions in the hope that forms might be found whose structure would indicate responsibility for some of the imprints. This search was not entirely in vain, for in the Permian *Araeoscelis*

with its light body, long, slender limbs, and lizard-like foot structure, we have a reptile which fulfils all essentials for the type of animal that made the tracks designated *Dolichopodus tetradactylus;* and in *Trematops* and *Cacops,* with wide, short bodies and short, heavy limbs, are amphibians of the right proportions to have made trails similar to those called *Baropezia eakini* and *Agostopus matheri.* I do not wish to imply that the tracks were made by these animals, but the type of creature to which they may be attributed is quite certainly represented. The evidence for such correlation must not be taken too seriously, since at present there seems no way of definitely linking up the two lines of evidence.

No strictly bipedal animals have yet been found in this fauna, all being quadrupedal, and these vary greatly in size from one of a few inches in length to the largest which may have attained a length of several feet.

Attention should be called to the fact that probably none of these trails shows the normal walking gait, due to the fact that all were impressed by animals climbing a steep slope in soft sand, and this effort has probably, in all instances, shortened the stride. That all of the trails observed, with one exception, lead in a common direction—that is, up the face of the slope—is difficult of explanation. This applies not only to the level where most of the collection was made but also to all other levels in the Coconino where tracks were seen, both perpendicularly and horizontally. It is also of interest to note that the three series of footprints of *Laoporus coloradoensis* from the Lyons sandstone of Colorado show the same characteristic.

The Ichnite fauna of the Coconino sandstone now consists of the following described genera and species:

VERTEBRATES

Dolichopodus tetradactylus, n. gen., n. sp.
Nanopus merriami, n. sp
Laoporus schucherti Lull
Laoporus nobeli Lull
Laoporus coloradoensis (Henderson)
Baropezia eakini, n. sp.
Agostopus matheri, n. gen., n. sp.
Paleopus regularis, n. gen., n. sp.
Barypodus palmatus, n. gen , n. sp.
Allopus? arizonae, n. sp.

INVERTEBRATES

Paleohelcura tridactyla, n. gen., n. sp.
Mesichnium benjamini, n. gen., n. sp.

The above fauna, taken as a whole, shows that its affinities lie nearest to those described from the Carboniferous Coal Measures rather than to the later Mesozoic Ichnites. This is indicated by the presence in the Coconino of two and possibly three genera common to the Carboniferous, whereas not a single genus of the Triassic was recognized. Furthermore, the facies of the fauna is Carboniferous in aspect as shown by the relatively small size of the animals, all of which are quadruped, as contrasted with the considerable number of very large forms and the many three-toed bipedal animals of the Triassic. The Coconino footprint fauna also seems to have closer relationships to the Ichnite fauna from the Middle Coal Measures of Kansas, described by Marsh[1] than to the more extensive faunas from the Coal Measures of Nova Scotia described by Dawson[2] and Matthew.[3]

The present fauna is founded upon specimens having well-marked characters, and being from a single locality and well-established horizon, have a value of their own in throwing light upon the land vertebrate life during the deposition of the Coconino sandstone. If they have but little value in themselves, they may eventually shed much light on the habits and characteristics of the Permian animal life.

PSEUDO-TRACK-LIKE MARKINGS

Plate 2, fig. 2

Under this heading attention is called to some peculiar track-like markings found on a massive sandstone of the Supai formation in that part of the Grand Canyon known as " Fossil Bay." While these are not regarded as having been made by animals, they are of interest on account of their superficial resemblance to tracks made by horses' hoofs, and since their origin is as yet unexplained, these notes are published in the hope that it may lead to a fuller investigation.

These markings were called to my attention by Mr. Samuel Hubbard, leader of the Doheny Scientific Expedition of 1924, who had long known of their existence through information obtained from the Supai Indians who regarded them as tracks made by a band of horses. They thickly cover an area of several hundred square feet in extent and have the appearance of semi-oval rings, frequently with the two posterior extremities prolonged backward, but seldom con-

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[1] Marsh, O. C., Amer. Journ. Sci., Vol. 42, 1894, pp. 81-84.
[2] Dawson, J. W., Geol. Mag. London, Vol. 9, 1872, p. 251.
[3] Matthew, G. F., Canadian Rec. Sci., Vol. 9, No. 2, 1903, p. 105.

verging sufficiently to meet behind. All the rounded or oval ends, as may be seen in the illustration (pl. 2, fig. 2) are pointing in a common direction. They vary in size but their general contours are fairly alike.

None of these markings occurred in regular sequence and none was found giving evidence of having been impressed into the surface of the sand. After a careful examination it was my conclusion that they do not present a series of fossil tracks, but were nothing more than a staining of the sandstone, the deeper coloration making them

Fig. 23.—*Hoplichnus equus* Hitchcock. Doubtfully regarded as animal tracks. 1/7 natural size. (After Hitchcock.)

stand out clearly against the lighter colored background of sandstone. A few through weathering showed surface depression but a section obtained in one place clearly indicated that this deep coloration extended downward into the sandstone for at least four inches.

In a search of the literature in an attempt to get light on the origin of these curious markings, it was of interest to find that Hitchcock[1] had described supposed tracks (see fig. 23) from the Triassic of Connecticut which bear a striking resemblance to those under consideration. Their resemblance to a horse's hoof was apparently recognized

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[1] Hitchcock, Edward, Ichnology of New England, 1859, p. 134, pl. 24, figs. 3 7.

by Hitchcock who applied to one the name *Hoplichnus equus*. Although unable to reach any conclusion as to the class of animals to which they might be attributed, Hitchcock was of the opinion that they were true tracks and not discolorations. He attempts to show that they occurred in regular sequence and were depressed below the general surface level. Hay[1] remarks: " It is doubtful whether or not this genus of foot marks was produced by a vertebrate animal."

Sir William Jardine described some hoof-like tracks from the New Red Sandstone of Scotland under the name *Chelichnus gigas*.[2] While these have the same hoof-like shape without the appearance of toes or claws, they do show a distinct pace and uniform alternate progression.

May it not be that the Supai markings are stains resulting from the decay of some gelatinous medusa-like animals that were stranded on a sandy beach?

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[1] Hay, O. P., Bull. 179, U. S. Geol. Surv., 1902, p. 546.
[2] Ichnology of Annandale, 1853, p. 9, pl. 1.

EXPLANATION OF PLATES

Fossil footprints *in situ*, Grand Canyon National Park.

(For explanation, see page 40)
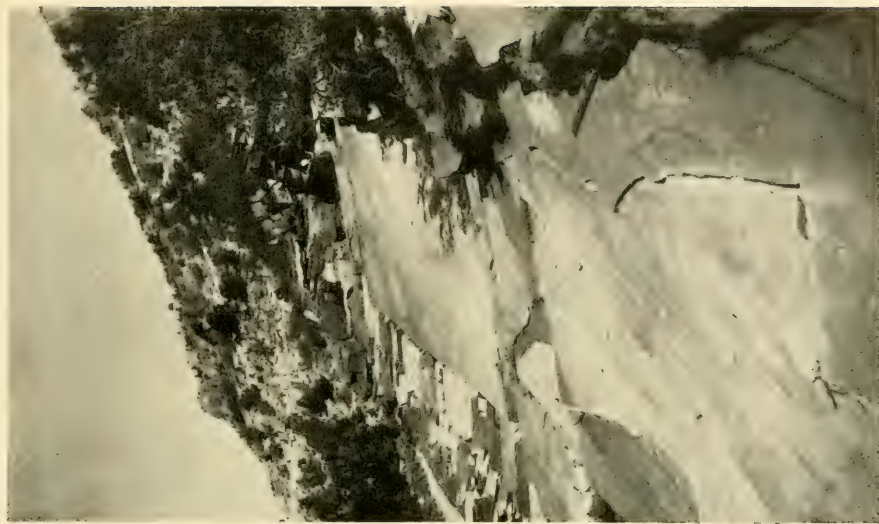
1

2

Above, Transporting slabs of fossil footprints.
Below, Unidentified track-like markings, Grand Canyon National Park.
(For explanation, see page 40)

General view of fossil footprint locality, Grand Canyon National Park.

1   2

Fossil footprints from the Grand Canyon.

(For explanation, see page 40)

1

2

Fossil footprints from the Grand Canyon.
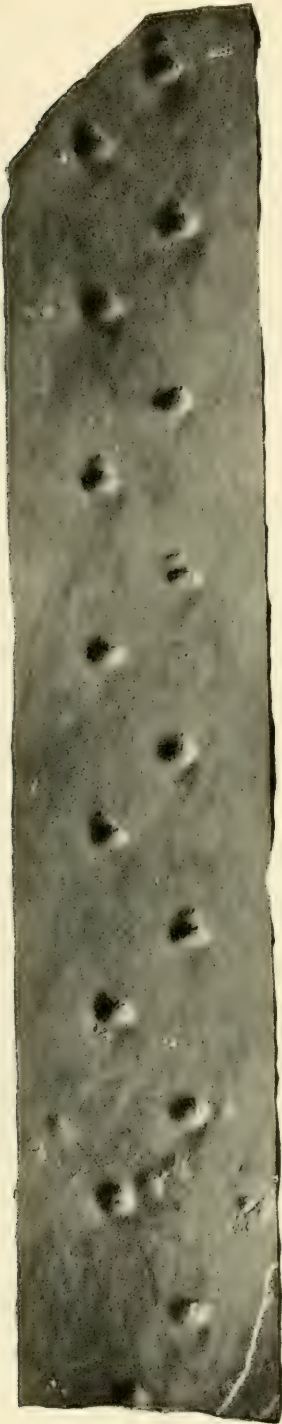
(For explanation, see page 40)

Fossil footprints from the Grand Canyon.
(For explanation, see page 41)

1

2

Fossil footprints from the Grand Canyon.

(For explanation, see page 41)

Fossil footprints from the Grand Canyon.
(For explanation, see page 41)

Fossil footprints from the Grand Canyon.
(For explanation, see page 41)

Fossil footprints from the Grand Canyon.

(For explanation, see page 41)

1

2

Fossil footprints from the Grand Canyon.
(For explanation, see page 41)

1

2
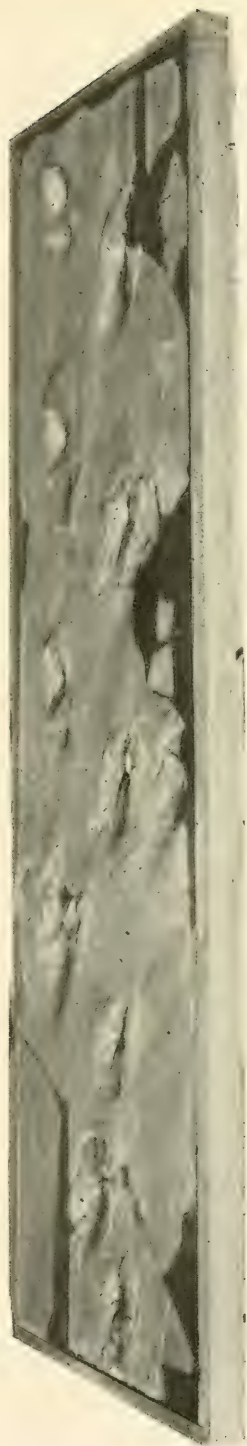
Fossil footprints from the Grand Canyon.

(For explanation, see page 41)

AN ARCHEOLOGICAL COLLECTION FROM YOUNG'S CANYON, NEAR FLAGSTAFF, ARIZONA

(WITH NINE PLATES)

BY
J WALTER FEWKES
Chief, Bureau of American Ethnology

AN ARCHEOLOGICAL COLLECTION FROM YOUNG'S CANYON, NEAR FLAGSTAFF, ARIZONA

By J. WALTER FEWKES

CHIEF, BUREAU OF AMERICAN ETHNOLOGY

(WITH NINE PLATES)

Notwithstanding the important articles on Southwestern antiquities that have been published during the past decade, we are still on the threshold of the subject. Many generalizations thus far suggested are provisional and must so remain until more comprehensive knowledge is available to provide broader foundations. We are greatly in need of field-work in several little-known localities, and one or two specimens are not sufficient to warrant conclusions that have been drawn from such limited comparisons. One of the least known of these uninvestigated areas of our Southwest, but one that bids fair to yield instructive results bearing on the solution of important problems, lies in Arizona, extending down the eastern slope of the San Francisco mountains and ending in the foothills on the left bank of the Little Colorado. These mountains are called by the Hopi Indians Nuvatikiobi, or The Place of the High Snows. Lying in full sight of the Hopi mesas, they are associated with many Indian migration legends and important Hopi ceremonials. A few miles from the left bank of the river, at Black Falls, there are clusters of high stone buildings with massive walls that are among the best preserved prehistoric monuments of our Southwest, and although well known to local students, they have been overlooked by some of the latest writers on the archeology of the Southwest. Fortunately, however, these little-known buildings have been officially recognized, and are beginning to attract the attention of students. The most striking of the ruins have lately been grouped by a proclamation of the President into a National Monument under the name of Wupatki, a word applied to them long ago by the Hopi Indians.

The history of these ruins is rather brief. They were first mentioned in 1853 by Sitgreaves, but for many years after no printed reference was made to them; in 1900 the author figured and described these buildings in an article in the American Anthropolo-

gist,[1] which was later quoted in a more comprehensive work on " Two Summers' Work in Pueblo Ruins."[2] Still later (1904), in " Records of the Past,"[3] a plea was made for their preservation as a National Monument. These studies were especially limited to architectural features, and little was said in them about minor antiquities. Through a fortunate circumstance the author is now able to add a few facts to our knowledge of the artifacts of this region.

During the past year, in constructing a road near Flagstaff, Arizona, it was necessary to remove an artificial mound, the contents of which revealed a prehistoric cemetery. A number of mortuary

Fig. 1.—Diagram of excavations in cemetery at Young's Canyon.

objects, mainly pottery, were exposed by the workmen, and although in the beginning some of these objects were lost, it so happened that Mr. J. C. Clarke, of Flagstaff, heard of the discovery in time to rescue many specimens. These he transmitted to the Bureau of American Ethnology, and they were later transferred to the U. S. National Museum. Although the collection is small, it was a very welcome accession, not only because there were in the Museum but few specimens from this locality, but also because some of the ob-

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[1] Amer. Anthrop., Vol. II, No. 3, pp. 422-450, 1900.

[2] 22d Ann. Rept., Bur. Amer. Ethn., p. 3, 1903.

[3] A cluster of Arizona ruins which should be preserved. Records of the Past, Vol. III, pt. 1, pp. 3-19, 1904.

jects are unique. The author regarded this addition as so important that he has prepared the following account as a contribution to a little-known subject.

Only three collections from this region are known, one now said to be in California (Southwest Museum), made by Mr. Benjamin Doney [1] before 1900, and another made by the author about the same time, which is in the U. S. National Museum. Neither of these collections has been published, although they contain highly instructive objects. There is a small unpublished collection at Flagstaff. When Mr. Clarke submitted the present collection he sent the writer a catalogue, which is here published with a few unimportant changes. The general forms of the pottery are shown in the accompanying plates (pls. 1, 2, 3).

CATALOGUE [2] OF THE OBJECTS FROM A MOUND AT YOUNG'S CANYON, NEAR FLAGSTAFF, ARIZONA

GRAVE NO. 1

1. Dark red ware food bowl.
2. Dark red ware food bowl.
3. Dark red ware food olla.
4. Dark red ware pot, with flat bottom, cracked.
5. Bottom of a corrugated vessel.
6. Dark red ware ladle.

GRAVE NO. 2

No object was found in this grave, but there was evidence that a badger had worked through it.

GRAVE NO. 3

7. Gray (white) ware food bowl, painted inside (broken and repaired).
8. Dark red ware bowl.
9. Dark red ware bowl.
10. Dark red ware olla.
11. Dark red ware olla. There is a blister on one side of the bottom, probably formed in burning.

[1] Mr. Benjamin Doney made extensive excavations in several of the ruins near Flagstaff, and acquired a considerable collection which the author examined in 1900. This collection, according to the author's information, was sold in California and has not been published. When the author examined it, he was much interested in several valuable specimens.

[2] Prepared by Mr. J. C. Clarke, of Flagstaff, Arizona.

GRAVE NO. 4

12. Dark red ware bowl (broken, part gone).
13. Dark red ware bowl (broken and repaired).
14. Dark red ware olla.

GRAVE NO. 5

15. Gray ware food bowl with handle; painted inside, cracked.
16. Gray ware bowl, painted inside.
17. Bowl of a ladle, painted inside (handle broken off and lost).
18. Dark ware pot.
19. Small dark ware olla.
20. Small dark ware olla.

GRAVE NO. 6

21. Dark ware jar, with slightly flaring rim.
22. Dark ware bowl.
23. Gray ware bowl, painted inside (handle broken off).
24. Gray ware bowl, handled, painted on inside (broken and repaired).
25. Rough ware jar, handled.[1]

GRAVE NO. 7

Contained nothing.

GRAVE NO. 8

Contained nothing.

GRAVE NO. 9 [2]

26. Ladle.
27. Ladle (grooved handle).
28. Dark ware bowl (broken and repaired).

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[1] This pot contained a double handful of vegetable matter resembling decayed food. The pot was covered with a piece of broken pottery on which lay one-half of a bivalve shell measuring $5\frac{1}{4}$ inches long by $4\frac{1}{2}$ inches wide.

[2] This must have been the grave of a person of some importance, as around the neck of the skeleton was a " dog collar " necklace (pl. 9) consisting of 565 mussel shells. There seemed to have been a shell necklace to which were attached short strings of shells.

At the waist line on the right side were 19 small arrow points of smoky topaz, 21 perforated olivella shell beads (one of which did not have the end

29. Dark ware bowl (cracked).
30. Dark ware bowl.
31. Dark ware bowl.
32. Dark ware bowl.
33. Dark ware bowl.

GRAVE NO. 10

34. Small corrugated pot (handle gone).
35. Bowl of dark ware ladle, without handle.
36. Rectangular dark ware dish (fig. 2).[1]
37. Gray ware bowl, painted inside.

Fig. 2.—Square food bowl of red ware with polished black interior. (Size: $3\frac{1}{8}''$ long x $2\frac{7}{8}''$ wide x $1\frac{5}{8}''$ high.)

38. Small dark ware ladle, handle broken.
39. Small dark ware bowl.

ground off so that it could have been strung), two beads, and a small piece of polished but undrilled turquois.

About half way between the hip and the knee on one side was another cache that contained 14 obsidian chips, a conical shell, $1\frac{3}{4}''$ long (has the long end ground off), and a cone-shaped piece of red sandstone $1\frac{1}{2}''$ long.

On the left side of the body about the waist line there were two large bone awls, one of which is nearly $9''$ long, and the other about $7\frac{3}{4}''$ in length.

There was a clay ladle on each side of the head, these being numbered 26 and 27. A picture of No. 26 taken from two positions is shown (pl. 6).

[1] This bowl (fig. 2) is rectangular in shape, containing a fragment of white "paint." Lying by the side of this paint was the end of a painted wooden object, probably a prayer stick. The wood is badly decayed, but the paint has so preserved the surface that its shape may be seen and the object identified. It measures slightly over an inch in length and is about $\frac{3}{4}$ of an inch wide.

GRAVE NO. 11 [1]

40. Small dark ware olla.
41. Large dark ware olla (badly cracked).
42. Large gray ware bowl, painted inside (badly broken, part absent).
·43. Gray ware bowl, painted inside; a lump of white "paint" adhered to the bottom.
44. Gray ware bowl, painted inside.
45. Dark ware bowl, chipped.
46. Dark ware bowl.
47. Small corrugated pot.
48. Small dark ware olla.
49. Small dark ware bowl.

GRAVE NO. 12

50. Corrugated olla.
51. Gray ware bowl, painted inside.
52. Small dark ware bowl.
53. Small dark ware bowl.
54. Small dark ware bowl.

GRAVE NO. 13

Contained nothing.

GRAVE NO. 14

55. Dark ware ladle, short handle (broken and repaired).

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[1] This was the grave of a child. On the lower left arm bones of the skeleton were eleven shell bracelets.

There was a flat bone object (pl. 8, *a, b*) lying lengthwise from the forehead of the skull towards the back of the head, just as if it had been worn in the hair, but the dirt settling on it had broken it in three pieces. Upon cleaning and matching the pieces together I found that the surface had been etched or engraved the entire length. It measures ten inches in length and is about $\frac{3}{4}$ of an inch wide at the butt end. In the soil several inches above the skeleton there was found the broken butt end of a wide awl-like object, the surface of which had been etched. This piece is only about four inches long and one inch wide. The position of the objects, as well as their form and incised decoration, tend to the conclusion that they were ornaments to which feathers were attached and worn in the hair.

An attempt to interpret these objects by the study of modern survivals will be found in the following pages.

GRAVE NO. 15

56. Dark ware bowl.
57. Dark ware bowl (cracked).
58. Dark ware ladle.
59. Dark ware bowl.
60. Dark ware bowl, chipped (broken and repaired).
61. Dark ware bowl, chipped.

GRAVE NO. 16 [1]

62. Reddish ware bowl, handle broken.
63. Bowl of a dark ware ladle, handle gone.
64. Gray ware bowl, painted inside (broken and repaired).
65. Corrugated bowl (badly broken and repaired).
66. Dark ware bowl, cracked.
67. Dark ware bowl.
68. Corrugated pot.

GRAVE NO. 17

69. Dark ware olla.
70. Dark ware olla, chipped.
71. Dark ware bowl.
72. Dark ware bowl.
      (Nos. 71 and 72 were nested.)
73. Dark ware olla.
74. Dark ware olla, chipped.
      (Nos. 73 and 74 were nested.)

FROM SEPARATE LOCATION

75. Small dark ware pot.[2]

[1] This grave contained the skeleton of a woman. The body had been buried face down and on her back and shoulders was the badly decayed skeleton of a child, indicating that mothers carried their small children on their backs as the Hopi do today. There was a small corrugated pot (No. 68) between the knees, and on the outside of the right leg was a "lignite button" measuring 2½ inches in diameter. This button had two parallel grooves, leaving a ridge between the grooves through which a small hole had been drilled from each side of the ridge until the holes met, thus affording a chance to suspend it.

[2] This small pot had been used as a burial urn, as it contains some of the burned bones of a child; a molar tooth and sections of the skull can be easily recognized.

Mr. Clarke adds the following notes:

"The discovery of this pot was the main incentive that the work should be watched, for I have in my possession two other pots that have been used for this

COMMENTS ON THE COLLECTION

POTTERY

The collection catalogued above is the first from the Flagstaff region yet published, and contains more significant objects from that area than occur in any other eastern museum. It is particularly important, as it may be used in comparisons with other collections from better known regions of the Southwest, and thus shed some light on the relation of the culture of the aborigines of the Little Colorado and other pueblo areas.

The following among other types of pottery were recognized:

1. Corrugated ware (pl. 1, *g;* pl. 2, *d;* pl. 1, *f*—neck coiled).
2. Rough undecorated ware.
3. Red ware with glassy black interior (pl. 2, *a, b, c*).
4. Undecorated red ware (pl. 1, *h, i;* pl. 3, *b, c, d*).
5. Black and white ware bowls, painted on the inside with black geometrical decorations (pls. 4, 5).

The majority of the pottery objects are food bowls, but there are also vases, ladles, and other forms (see pls. 1-3 and catalogue).

The designs on the ware are among the most important for comparisons, and as little attention is given to this feature in the catalogue, the author has introduced the characteristic representations on the accompanying plates (pls. 4, 5). In the author's judgement, figures on this black and gray ware are among the most striking, from an artistic point of view, of any in our Southwest. None of the bowls bears naturalistic designs or those representing men or animals.[1]

same purpose. This pot and contents (75) came from the same place where I caught a fellow digging a couple of years ago, who a few days later sold me the two pots I have and while he would not admit getting anything, I am confident that I am right in my supposition. I am very sorry not to have found one of the larger ones, as I am sure that you would have been interested in the discovery as I have been unable to find anywhere a record of cremation having been practiced in the Little Colorado Valley.

" The following pieces have not been listed:

    6 fragments of bone awls;
    1 fragment of lava that had been hollowed out to use as a mortar;
    5 hand stones that are in good shape;
        several broken hand stones;
        several pieces of broken shell bracelets;
    5 whole shell bracelets;
    1 piece of cherry colored stone, polished, about the size of a large plum;
        potsherds of different colors."

[1] This is also true of the majority of decorations on black and white ware from the San Juan Valley.

The pottery specimens, although mortuary, bear no indication that they were purposely perforated or "killed," a custom so common in the Mimbres and in certain other areas of the Southwest, and there are no specimens showing the broken encircling lines, a feature likewise unknown in pottery from the Mesa Verde and the San Juan Valley. This failure is instructive, as the presence of the broken line is so common higher up on the Little Colorado, at Homolobi (Winslow), and Hopi ruins, Sikyatki, Awatobi, and along the Antelope Valley.[1] There are no effigy jars or attempts at relief decoration. No designs were noted on the exteriors of the bowls, a feature so common at Sikyatki, Homolobi, and other ruins in the middle valley of the Little Colorado. Although the interiors of the decorated bowls are in the main white in color with black designs, the author has collected from near the great buildings in Wupatki examples of what may be called a polychrome ware, mostly dull red bowls, on the inside of which occur designs similar to these here depicted. These designs correspond in color to bowls from the Marsh Pass Region.[2] We find only occasionally that they are enclosed in a framework of encircling lines, but cover the whole interior of the bowl with the exception of a central area which may be circular or rectangular, but destitute of figures. The majority of the designs are formed of four units which may be the same or unlike, sometimes arranged in pairs. In certain examples we find figures in white on a black ground. Although the designs are all geometric, rectilinear and curved component lines are about equal in number.

It will be noted that in several of the figures the black color in the design is greater than the white, or in other words the decoration may be said to be in white on a black background, which is so striking in plate 5, *b*. This tendency of "negative" figures on black ground appears also in designs from the Mimbres Valley, Tokonabi (Kayenta) ware[3] and is also shown in the beautiful vase, the finest known to the author[4] from the Chevlon ruin. The designation "heavy

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[1] It is highly probable that this custom was introduced from the south (Lower Gila), but it occurs on ancient ware from Jemez. A modified form occurs on Chaco Canyon ware and elsewhere. It can hardly be possible that such a specialized feature as this could have developed independently, and its absence in the oldest ware is significant.

[2] Kidder, pl. 32, "Introduction to the Study of Southwestern Archeology,"[6] figures six designs typical of his Kayenta ware, which are almost identical with those shown in plates 4 and 5 of this article.

[3] *Ibid.*, pl. 31.

[4] 22d Ann. Rept., Bur. Amer. Ethn., pl. XX.

black " (Kidder) design on white ware might give place to mosaic white decorations on black background, or simply white figures on black, where the design is in white, the black base serving to show its form.

The use of black bands, either straight or curved, with rows of dots as an ornamental *motif* is an instructive feature in the pottery, although duplicated in other ceramic areas.[1] Commonly these rows of dots are symbols of corn, but here the design is probably an ornamental rather than a symbolic one. Attention may be called to the effective arrangement of the bands with spots into four units with double rows of rectangular nucleated spots shown in plate 5, *a*. The white spots on a black ground reappear in plate 5, *d*. In plate 5, *c,* there is a dual arrangement, a departure from the uniformity of the four units in the quadrate design, and in plate 4, *d,* one is different from the other three.

LADLE WITH HANDLE MADE INTO A CRADLE WITH INCLOSED FIGURINE

The most exceptional piece of pottery from the Young's Canyon cemetery is a black and white ware ladle, the sides and end of the handle of which are pinched up and modified into a cradle containing a small clay figurine,[2] shown from above and the side in plate 6.

Another example of a ladle with a cradle on the handle was formerly owned by Mr. Frank Wattron, of Holbrook, Arizona, who purchased it from a Mexican pot hunter. The ruin in which this object was found is unknown. The specimen was sold, with the Wattron collection, to an agent of the Field Columbian Museum of Chicago. While it was still in possession of Mr. Wattron, in 1897, the author made two drawings of it, which are here reproduced (pl. 7).

Clay figurines of like shape, separated from cradles, have been found by the author in localities higher up on the Little Colorado, showing that although these ladles are rare, they were not unknown in prehistoric households of this portion of Arizona. The little images on their handles can hardly be called fetishes, but were more in the nature of dolls. Attention may be invited to a well-known habit of modern Indian mothers: Several Hopi ladles are known in which the handle

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[1] This form of decoration occurs in the Chaco Canyon, Casa Grande, and other ruins.

[2] It was formerly not unusual to find, in collections of Hopi pottery, ladles, the handles of which were moulded into rude effigies representing the clowns who accompany the Katcina, or even Katcinas themselves. These have apparently gone out of use, and belong to the Hopi ceramic epoch, antedating the author's excavations at Sikyatki (1895).

is hollow, with small stones in the cavity, converting the handle into a rattle, suggesting a baby's rattle.[1] At times these were probably shaken to divert the attention of the infant, but the noise produced by such a rattle could hardly have been loud enough for use by dancers, who also often use rattles, frequently described by students of the ceremonial dances of the Pueblo Indians. Years ago the author collected a ladle of prehistoric date, on the handle of which a human figure was painted. The intention of this was practically the same as that of the clay image in an imitation cradle above described. There seems no doubt that these objects were used simply as toys to amuse children, and when the images are found separated from the ladles they have no sacred intent or character.

Of the specimens of ladles with handles modified into cradles, that shown on plate 7 is apparently better made and more highly ornamented than the specimen (pl. 6) from Young's Canyon. The bowl of the former has its interior decorated by a band with checkerboard pattern and there are two symbolic figures of rain clouds that do not appear in the ladle from Young's Canyon. It also shows a "broken line" called the "life gateway," so common in pottery taken from the Gila Valley and ruins on the Middle Little Colorado, as well as at Sikyatki and other ancient Hopi ruins. As this specimen is classed as black and gray (white) ware it is supposed to belong to the older types chronologically, but attention should be called to the fact that this break in its surrounding lines is wanting in the black and white ware of the San Juan ruins, and the evidence seems to be that the broken line shows the influence of another prehistoric epoch.

One of the characteristics of the author's sketch of the figurine in the Chicago specimen are the black marks that are drawn across the face on either side, from the corner of the eyes and mouth to the region of the ears. This is a common facial decoration of certain personators in the sacred dances of the Hopi known as "clowns" or Tatcukti, who are said to have come to Walpi from the south.[2] In a dance that occurs in November, at the East Mesa, they carry phallic symbols and are called Tataukyamu.

Clay effigies identical with those in the handles of these ladles, but free from them, were collected by Kidder and Guernsey on the surface near Ruin A, in the Marsh Pass region, Arizona. Their use

[1] 22d Ann. Rept., Bur. Amer. Ethn.
[2] There are three different kinds of "clowns" at the East Mesa, called *Tatcukti, Koyimce,* and *Paiakyamu.* The last mentioned are Tanoan; the second, Zuñi.

was not determined and it was stated by these authors that " Nothing resembling these figures has ever been found, so far as we know, in the San Juan drainage, and nothing exactly like them anywhere in the Southwest." [1]

STONE BURIAL CYSTS AT WUPATKI

Shortly after publishing his account of the Black Falls ruins, the author made a few excavations near the large buildings and found several good examples of the stone burial cysts similar to those described in the Marsh Pass (Tokonabi) region by Kidder and Guernsey.[2] The sides of these cysts were made of stone slabs set on edge, and each enclosure had a stone slab for a cover. The pottery found in these graves had the same character, and bore designs like those here described from Young's Canyon. The identity of this mode of burial and its association with a massive walled building reminds one of the Ruin A in the Marsh Pass area. The form of the great building, Ruin A, and those of the Black Falls, is apparently the same, but the use is not as yet satisfactorily determined.

BURIAL URNS AND CREMATION

Mr. Clarke calls attention to calcined human bones in mortuary vessels which appear to have been burial urns [3] like those found at Casa Grande, elsewhere mentioned by the author. Cremation was a method of disposal of the dead, and is also reported by Mr. F. W. Hodge from Hawiku in the Zuñi Reservation.[4]

BONE ORNAMENTS FOR THE HEAD

The collection contains a few bone objects, such as needles, bodkins, and the like, which do not differ greatly from those found in

[1] Bull. 65, Bur. Amer. Ethn., p. 144.

[2] These cysts were of circular or oval form containing human bones, skull, and mortuary offerings.

Similar burials were discovered many years ago by Baron Nordenskiöld in Step House on the Mesa Verde. (Cliff Dwellers of the Mesa Verde, 1893.) The existence in Step House cave of prepuebloan as well as puebloan culture was pointed out by the author in Smithsonian Misc. Coll., Vol. 72, No. 15, 1922.

[3] *Vide* note on contents of Grave No. 17, specimen No. 75. This is a very good example of the ease with which archeological objects may be interpreted by modern ceremonial survivals, a method at present greatly neglected by writers on pueblo chronology.

[4] Castaneda records cremation among the Cibolans (Zuñi) in his account of the Coronado Expedition (1540). Winship, 14th Ann. Rept., Bur. Amer. Ethn.

other ruins on the Little Colorado, but two rare broken specimens are worthy of special attention. They are made of polished bone, decorated with superficial incised ornamentation clearly indicated in the accompanying figures (pl. 8, *a, b*).

The objects, as stated in the catalogue, lay on or near a human cranium, a position indicating that they were hair decorations, and they are probably the same as the so-called *herunka,* or feathered head ornament, worn on the crown of the head by warriors or by the personators of the Little War God. Similar objects still survive in pueblo ceremonies. One of these (pl. 8, *c*), collected by the

Fig. 3.—War God and complemental female idol on the Oraibi Snake Altar.
a, God of War wearing netted cap and bone hair ornament.

author at Zuñi in 1890, is shown in his account of " A Few Summer Ceremonies at Tusayan." The bone shaft by which this was attached in the hair was decorated with bird feathers and a fragment of abalone shell. A similar hair ornament is attached to the cap of an idol of the Little War God on the Oraibi Snake Altar, as shown in figure 3.

SHELL BRACELETS

Shell bracelets, armlets, and finger rings made of Pectunculus and other marine shells were very common in graves at Homolobi, Chev-

lon, and other ruins on the Middle Little Colorado, and were probably obtained from the Pacific Coast tribes. In prehistoric times there appears to have been a lively trade between the Southwestern tribes in pottery, shells (pl. 9), blankets, turquoises, and other objects. Even at the present day traders from the eastern pueblos resort to the Hopi for the purchase of blankets, which are bartered in exchange for turquoises and other valuables. The author witnessed at the East Mesa in 1891 what was said to have been a survival of the ancient fair,[1] at which time a large number of pottery objects, native baskets, blankets, and other specimens were exposed for sale in the open space between Walpi and Sitcomovi, and a considerable number of Navajos and men from other pueblos were on hand as purchasers.

This interchange of material objects through barter was not limited to material objects, but songs, legends, prayers, rites, and ceremonies were also bought and sold, and thus traveled from tribe to tribe.

CONCLUSION

The author is conscious that this brief article is only a small contribution to the problems of pueblo culture, but it is an addition to our knowledge of an unknown area. One of the most important of pueblo problems is the interpretation of the sedentary culture of the Lower Little Colorado. We are in a fair way to have our knowledge of this area greatly enlarged by Professor Colton, who has already given much study to it and has published a very important article on the small house ruins. He has transmitted to the Bureau of American Ethnology for publication a still more comprehensive article.

The pottery from Young's Canyon resembles the poorly defined so-called prepuebloan found in the region north of the Hopi pueblos, and probably once spread over the greater part of what is now the State of Arizona. Similar pottery has a wide distribution, and has been reported from various points also in Colorado and New Mexico, but it is best represented on the Lower San Juan in the region called Tokonabi by the Snake people of the Hopi.

It will probably be found later that a culture not radically unlike that indicated by the ceramic and other objects from Young's Canyon, extended over the whole of Arizona north of the Mogollones from the Little Colorado to the San Juan, more especially in the eastern

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[1] The Hopi personate a Katcina called the Trade Katcina, which the author has seen and figured, but of whose function he is ignorant.

part, and over the border into New Mexico, where we find evidences of a more thickly settled region, indicating that incoming people from the north, east, and south had united with it or modified it, and formed a mixed pueblo people. The survivors of this mixture are represented by inhabitants of the modern Zuñi and Hopi pueblos, especially the latter, which have conserved to our own time the least modified cultural elements of the prehistoric Southwest. There are many areas where intensive archeological work, both chronological and cultural, is much needed, but not one which promises more than the region about Flagstaff.

The forms, colors, and designs on the pottery bowls figured resemble those from the Black Falls, which as the author has shown are similar to those from an area in northern Arizona known to the Hopi as Tokonabi. Like specimens occur in sites situated in the East Mesa Wash and elsewhere in ruins not yet described. The author suggests that the name Tokonabi be applied to the culture area, which is a very extensive one, in which the ruins here referred to are situated. Neither the types of artifacts or architecture nor the boundaries of this culture can be determined without more field exploration.
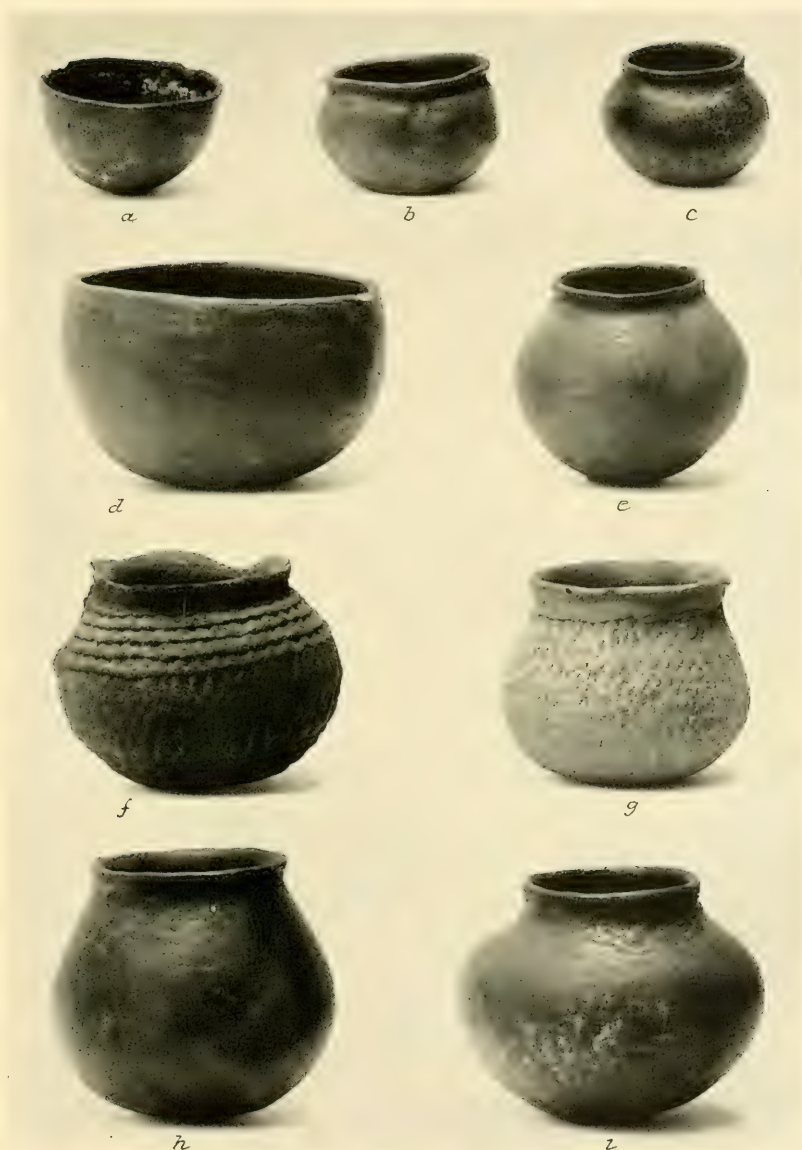
Vases and bowls. *a,* Black and white bowl with interior decoration; *b, c, e.* bowls with turned out edges; *d,* semi-globular bowl; *f,* corrugated ware with rim ornamentation; *g,* vase with incised decoration; *h, i,* undecorated red ware with black interiors. (Sizes: *a,* 2⅛" high, 3½" diam.; *b,* 2⅜" high, 3½" diam.; *c,* 2⅜" high, 3¼" diam.; *d,* 8¾" high, 4½" diam.; *e,* 3⅞" high, 4⅜" diam.; *f,* 3¾" high, 4¾" diam.; *g,* 3⅝" high, 4⅞" diam.; *h,* 4¾" high, 5" diam.; *i,* 4⅜" high, 5¾" diam.)

Pottery and bone implements from Young's Canyon cemetery, Arizona. *a*, Repaired broken bowl of red ware; *b*, bowl of red ware with black interior; *c*, food bowl of red ware with black interior; *d*, corrugated jar with one handle; *e*, *f*, bone needles. (Sizes: *a*, 3⅞" high, 7⅜" diam.; *b*, 6" high, 7⅜" diam.; *c*, 5¼" high, 8½" diam.; *d*, 7½" high, 8⅛" diam.; *e*, 9" long, ⅝" diam.; *f*, 8" long, ¾" diam.)
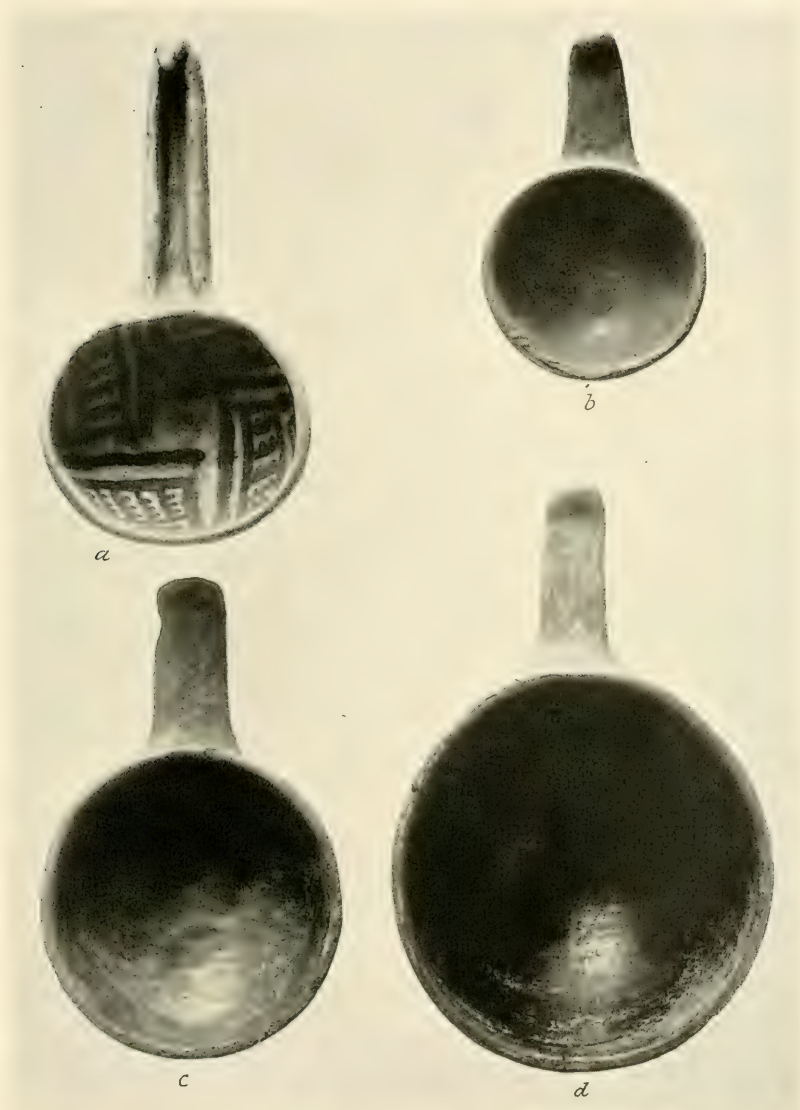
Ladles. *a*, Black and white ware with grooved handle; *b, c, d*, red ware with black interiors. (Sizes: *a*, bowl 3¾" x 3", handle 3⅜"; *b*, 2¾" in diam., handle 1⅝"; *c*, 3¾" in diam., handle 2⅛"; *d*, 4⅞" x 4⅝", handle 2¼".)
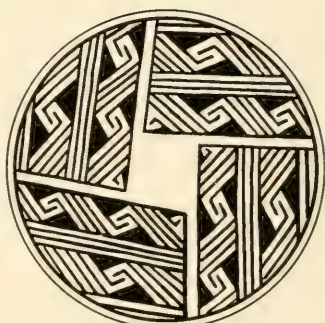
a, Design on ladle illustrated in pl. 3, a; b-f, typical geometric designs on five food bowls of white ware decorated with black lines. (Sizes: a, 3⅜" x 3", 1¾" high; b, 2⅞" high, 4⅞" diam.; c, 3⅝" high, 6¾" diam.; d, 3" high, 4¾" diam.; e, 5" high, 8¼" diam.; f, 4⅝" high, 8¼" diam.)
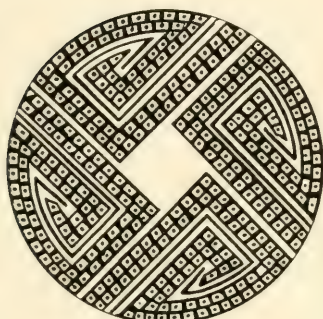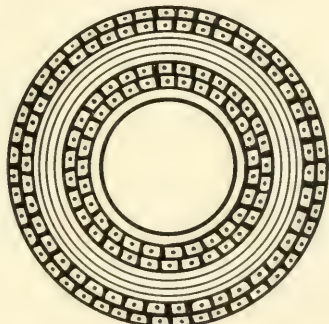
Decorated black and white ware. *b*, White or negative design on black base; *c*, interlocking spiral on interior of bowl of a ladle with handle broken off; *a, d, e, f*, geometrical designs. (Sizes: *a*, 3½" high, 6¼" diam.; *b*, 3¼" high, 6" diam.; *c*, 4⅞" x 4½", 2¼" high; *d*, 3½" high, 5½" diam.; *e*, 3½" high, 5¾" diam.; *f*, 2½" high, 4¾" diam.)

Black and white ware ladle with cradle handle, from Young's Canyon cemetery, Arizona. (Size: Bowl, 3⅜" x 3", handle, 3¾".)

Black and white ware ladle with cradle handle from ruin near Holbrook, Arizona.
(Field Museum, Chicago.)
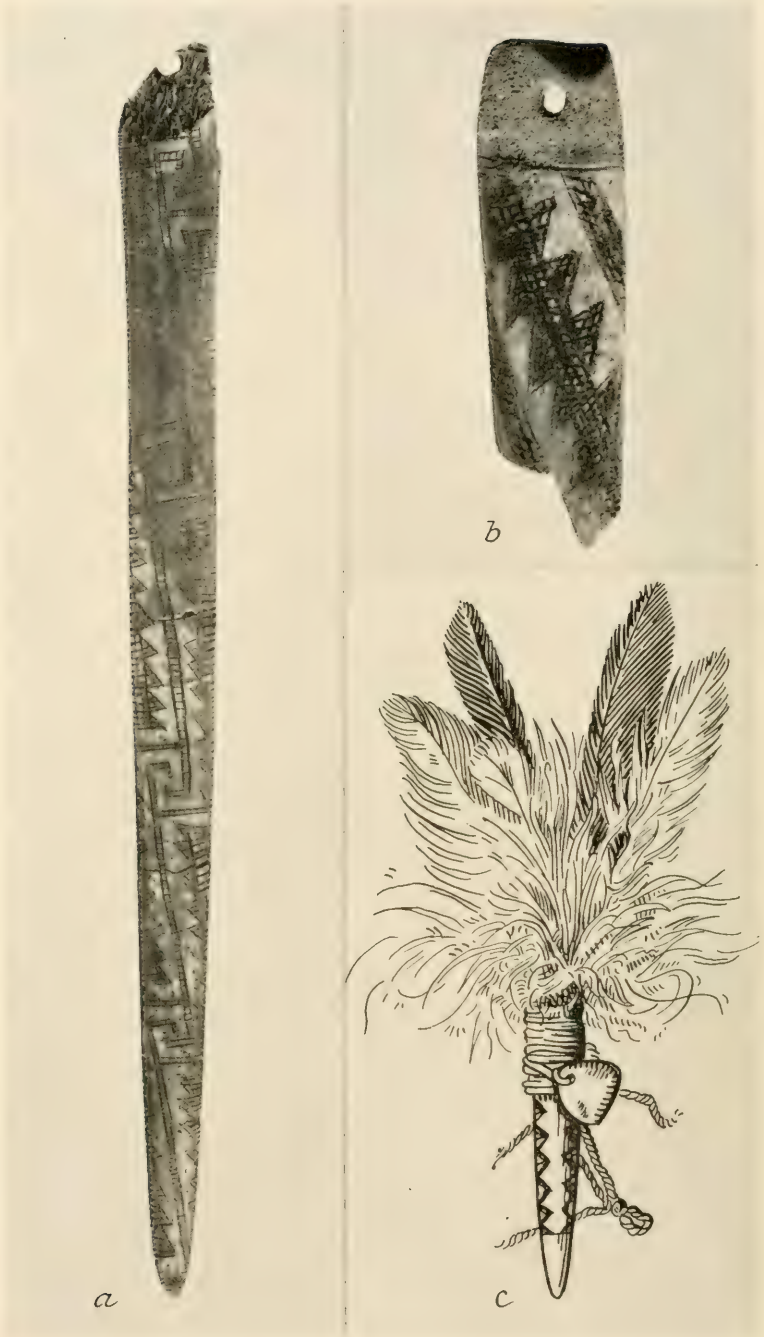
a, Bone hair ornament (herunka) with incised decoration found with a human skull; *b*, broken hair ornament with incised decoration; *c*, modern Hopi hair ornament with attached feathers and turquois; made of bone with incised decoration. (Sizes: *a*, 10⅛″ long, ⅝″ wide; *b*, 4″ long, 1⅛″ wide.)
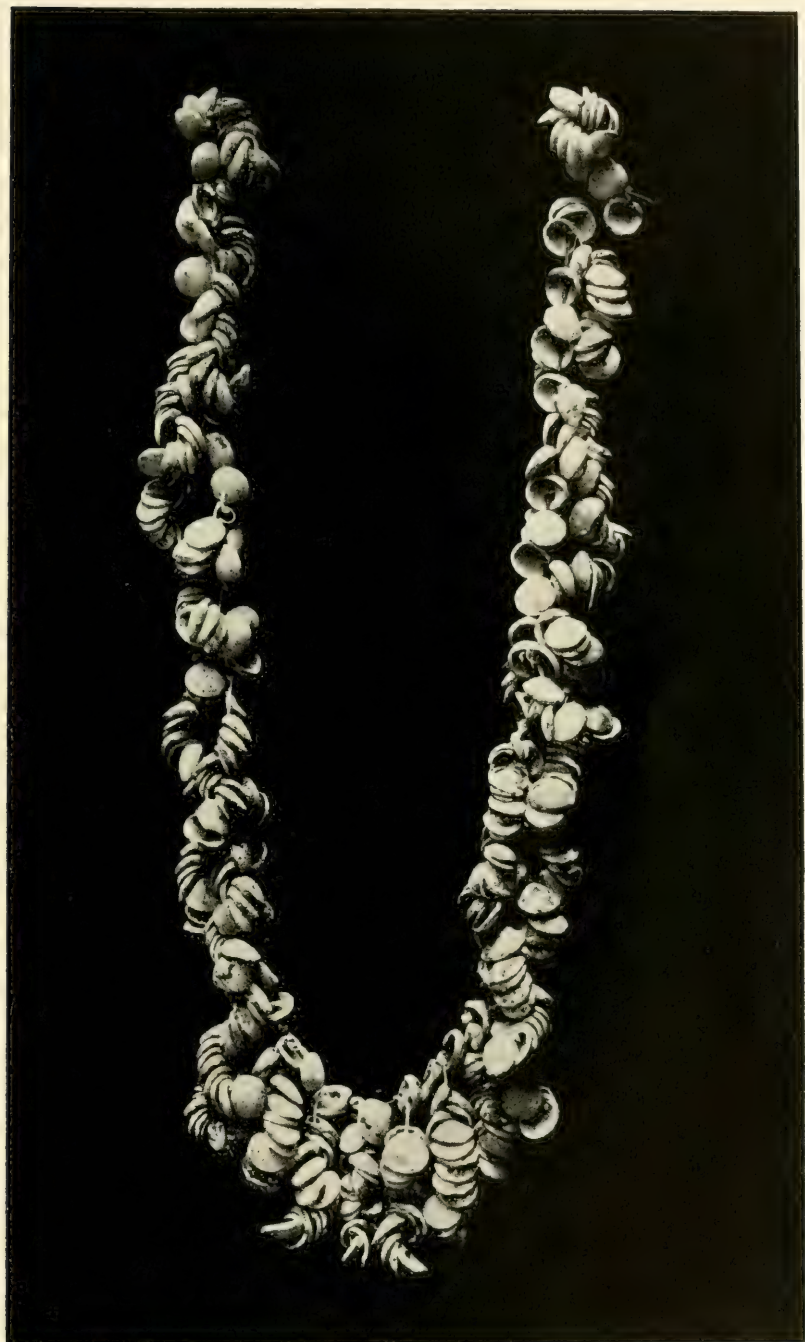
Necklace made of small shells found with a skeleton.

MUSIC OF THE TULE INDIANS
OF PANAMA

(With Five Plates)

BY
FRANCES DENSMORE

MUSIC OF THE TULE INDIANS OF PANAMA

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CONTENTS

INTRODUCTION

A remarkable opportunity for the study of primitive music was recently afforded by the presence of eight Tule Indians in Washington. These Indians were from the Isthmus of Darien in Panama and were brought to the United States by Mr. R. O. Marsh. The five adults in the group were of normal Indian color and the three children were fair, being examples of the " white Indians," whose occurrence among the Tule has caused the tribe to be known by that name. The Tule live on islands near the coast of the Caribbean Sea from San Blas Point to Armila, a distance of 120 miles. They also hold the San Blas Range of mountains on the mainland.

This study was done entirely with the adult members of the group during portions of November and December, 1924, and was made possible by the courtesy of Mr. Marsh. The work was under the auspices of the Bureau of American Ethnology, Smithsonian Institution.

TULE MUSIC AND MUSICIANS

The most important persons in a Tule village are the chief, the doctors, and the " official musicians." A chief may be also a doctor but the musicians seldom act in other than their own capacity. Each village has four such musicians, two of whom are known as the " chief musicians," and the other two as " assistant musicians."

These men know all the songs and teach them for pay when requested to do so. The four musicians do not attend the same gathering in their official capacity; thus at a wedding there is one chief musician and one assistant. At social gatherings there is only one singer, who sings alone for the entertainment of the people. He has no instrumental accompaniment, but six men standing in a row play on bamboo flutes during the prolonged tones of the song. Dancing is accompanied by two players on the panpipes, and the dancers often sing and clap their hands.

Distinct from the songs for entertainment, there are songs which aid in the accomplishment of a definite purpose. Such are the songs used in the treatment of the sick, and the songs used with the " charms " which are sold by the doctors. Music is not absent from the everyday life of the home and the women sing when at their work and sing to the little children. The words of all Tule songs are in the form of narratives. In the songs of the " official musicians " and the doctors the substance of the words is established, but the songs of the women are concerning their daily work or the work of the men on the plantations.

The principal musical instruments are the panpipes and flute which are easily made from reeds and bamboo.

There are " talented amateurs " among the Tule who learn the songs from the professional musicians but do not " sing in public," and who learn the songs used by doctors but do not treat the sick. Such a man is Igwa Nigdibippi (pl. 1) who recorded the Tule songs and instrumental music in Washington. Igwa said that he began the study of music when he was ten years old, learning a song from a teacher named Contule Nigdibippi, who was about 30 years of age. He learned the song that brings success in turtle catching (No. 5, page 27) and paid the teacher $15. It took him a long time to learn the song as the Tule have no written language and no musical notation. Seven years later he went to a man named Ina Yidepela, his first teacher having gone away in the meantime. He studied four years with this teacher, first learning a love song (No. 9, page 34), then the song concerning the boat race (No. 6, page 29), and then many miscellaneous songs including those concerning the sunrise, the sea lobster, river lobster, redheaded woodpecker, and the roach. After these he learned the songs that are used by medicine men, though he is not a doctor. He learned the songs to make medicinal herbs effective, the songs for the cure of headache and other ailments, and the songs that are sung after a man's death. In all, he acquired about 30 songs from this teacher.

Igwa Nigdibippi playing flute and rattle.

James Perry (recording), Margarita, his daughter, and
Alfred Robinson, the interpreter.

In the vocal and instrumental music of the Tule we have a form of music which, it is believed, has not previously been described. It appears that the substance of the words and the general character of the melody of each song is " learned," but that each performance of the song is an improvisation. This became evident in the recording of the songs and the Tule said they did not intend to " sing a song always the same." This is in direct contrast to the musical customs of the North American Indians and will be considered in a subsequent paragraph.

In observing the music of the Tule we note a standard of excellence, shown by the statement that some persons are good singers while others " cannot sing." It is also interesting to note that, except for songs intended to cure the sick, Tule music is connected with the happiness of life. There are no songs to give success in gambling, no songs connected with the food supply, and the " song of appeal to the supernatural," which is so important a phase of North American Indian music, is absent among the Tule. Games are played only by boys, the food supply is said to depend upon " treating the earth good " and living peaceful, upright lives, and the doctor sings of his remedies, not of an " unseen helper " who teaches him how to treat the sick. Tule music is connected with the pleasures of a simple, industrious people. The words of the songs are concerning the things they enjoy and are always in the present tense. The interest is sustained and it appears that the song always has a " happy ending." An exception may be found in the song that was sung after a man's death, but this was sung by a doctor for the consolation of the bereaved. The words of this song are sorrowful.

Associated with Igwa Nigdibippi in giving this information were James Perry, his wife Alice Perry, and Alfred Robinson who also acted as interpreter. The name " Perry " was selected by this man and his wife after their arrival in the United States and their native names were not obtained. Alfred Robinson had worked on a sailing vessel and been in Panama City, and said he had used this English name for many years. The fifth adult in the group had lived so long away from the tribe that he was not asked to assist in the present work.

The songs and instrumental music were recorded on a dictaphone. The group in plate 2 shows James Perry recording, Alfred Robinson at the right, and Margarita, daughter of Mr. and Mrs. Perry, standing. Mr. and Mrs. Perry are of normal Indian color while their daughter is of the type known as " white Indian."

VOCAL MUSIC

The tone production of the Tule is different from that of the North American Indian and both are widely different from that of the white man. The *vibrato,* which constitutes a musical accomplishment among the Indians, is entirely absent in the Tule whose tone is very hard, with a pinched, forced quality not pleasing to our ears and impossible to describe. It is an artificial tone which undoubtedly is difficult to acquire. There are no contrasts in volume, no " loud and soft passages," and strong accents seldom occur. The general character of the songs is pleasing, and the melody flows smoothly along except for prolonged tones (in some songs) during which the flute and rattle are played. These tones are usually at regular intervals, but there is sufficient flexibility so that the melody is not mechanical in its general form. A doctor uses no accompaniment with any of his songs. There appear to be no Tule songs connected with the history of the tribe nor its former chiefs. As they have never been at war, they have no war songs, and no songs are hereditary in a family, as in certain tribes of North American Indians.

Aside from the songs for entertainment, the charm songs and the home songs of the women, the occasions for singing were said to be the treatment of the sick, the scene after a burial, the maturity feast of a young girl and her wedding. Examples of all except the home songs and those of the maturity feast were recorded. It was said this festivity included singing, dancing, and gifts. Two men sang together, as at a wedding, and the number of flutes might be from two to seven. The girl's name was inserted in the song, two old men telling about her when she was a very little child, then following her life year by year down to this event. She wore a pretty dress with many strings of beads and fragrant berries. Her hair was cut, her cheeks were reddened and a fine red line was drawn down her nose. Many relatives came to assist at the feast.

The first song recorded by Igwa was the love song (No. 9, page 34), the second was that for relief of headache (No. 2, page 18), and the third was the song of the boat race (No. 6, page 29). About a week later the first and third of these songs were recorded again and it was found that the sets of renditions bore a general resemblance to each other but were not exact duplicates. Inquiry brought the statement already mentioned that they did not intend to sing the song always alike. On examining the two renditions of the song concerning the boat race it was found that the first was the better of the two. When making the second record Igwa was less at ease than when making the first record and the result was apparent in

his song. One disadvantage in improvisation is that the work is affected more or less by the mood of the performer. Realizing this necessity of ease when singing, an effort was made to have the Tule feel as much at home as possible in the writer's office and to avoid close questioning, which made them restive. They understood the desire to secure accurate information concerning their musical customs, and, assuming in part the responsibility of the research, they volunteered a large amount of information which it would have been difficult if not impossible to obtain under other circumstances.

Nine Tule songs were recorded, with four performances on the panpipes, and one on the flute, all being transcribed wholly or in part. The record of one song was about 15 minutes in duration while others were seven to nine minutes long. The first named required two dictaphone cylinders as the singer had been asked to record the song at length, but he usually watched the indicator and tried to condense the song into the space of one cylinder. An example of this abbreviation is noted in the description of No. 8, page 33. The songs which preceded the gathering of medicinal herbs and the song for the relief of headache were transcribed in full, but in the other songs it was not considered necessary to transcribe every tone. They contained passages of varying lengths which were not of musical interest, being either exceedingly monotonous or repetitions of single tones, while in some instances the intonation was so wavering that transcription was impossible. In these songs the interesting portions were transcribed and the omitted passages indicated by wavy lines. The transcription usually extended from the beginning to the end of the record, thus showing the melody as a whole although scattered passages were omitted. At frequent intervals the transcription was marked with the numerals on the space bar of the dictaphone. (See description of No. 6, page 29.)

The compass of Tule songs is considerably smaller than that of the songs of the North American Indians. Some Tule songs have a compass of only three or four tones, while others have a range of five tones with the occasional addition of a tone above or below the compass, sung lightly and seldom accented. The transcription should be understood as indicating the pitch of the tones as nearly as is possible in ordinary musical notation. The signature is used for convenience of observation and does not, in every instance, imply a scale-relationship between the tones. In the two songs transcribed in their entirety the intonation was fairly good throughout the performance while in some other songs it was variable. The apparent keynote is usually the lowest or next to the lowest tone, and the

third above it is usually major or minor, but the intonation is clearest on the fifth above the apparent keynote. An interesting peculiarity of intonation was noted in the song connected with medicinal herbs, occurring on the progressions transcribed as C-B natural—B flat. The singer divided the whole tone between C and B flat into four small intervals of about equal size, thus singing approximately " quarter tones." This did not occur in any of the other songs and does not appear to be important; no attempt is made to indicate it in the transcription. The freedom which characterizes all the music of the Tule does not suggest that they have an elaborate musical system containing fractional divisions of tones.

A distinct peculiarity of Tule music is a prolonged tone, occurring usually at regular intervals in the melody. For example, this prolonged tone in the song connected with medicinal herbs begins on the measures of the transcriptions which bear the following numbers (referring to the dictaphone space bar) : 2, 4, 6, 8, 10, $11\frac{1}{2}$, 13, 15, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 45, $46\frac{1}{2}$, 48, 50, 52, $52\frac{1}{2}$, $54\frac{1}{2}$. The length of the prolonged tone varies from two half notes to three half notes and a quarter note, this tone being followed by a pause which varies from a quarter to four half rests. The prolonged tone is usually the same throughout a song, and is generally the keynote which, as indicated, is the lowest tone except for an occasional, unaccented appearance of the tone below the keynote. In the wedding song there was music by flutes and rattles during the prolonged tones of the melody. It was said that flutes were similarly played during the prolonged tones of other songs and it is probable that the rattles were used with the flutes. The use of prolonged tones at regular intervals suggests a chant but the Tule songs bear no resemblance to chants. Instead, they suggest melodic speech in which the rhythm is determined by the accents and lengths of · the words.

Tule songs are not thematic in character. There are no recurrent phrases in the two songs transcribed in their entirety but we find two such phrases in the song entitled " Where the river begins," the phrases doubtless occurring with certain repetitions in the words. A short phrase occurs many times in the wedding song, but its connection with the words is not clear. The music follows the words which are usually a simple, continuous narrative. Accents were clearly given and the measure-lengths of the transcriptions are according to these accents. It will be noted that the measure-lengths include 2-4 and 3-4, as well as 3-8, 5-8, 6-8 and 7-8. The song with medicinal herbs contains five different measure-lengths.

Each song was prefaced by a few measures in which no words were sung. After this introduction and with the beginning of the words there was usually a change of tempo. It is interesting to note that the time was steadily maintained unless there was a decided change of tempo. Such a change was evidently connected with a change in the words. Thus in the song of the boat race there is a quickening of the tempo at the point marked 30 (dictaphone space bar), the words stating that the wind grows stronger and the captain of the boat is becoming alarmed.

The peculiarities of individual songs are noted in connection with the words of the songs.

INSTRUMENTAL MUSIC

The Tule Indians are unique among primitive people in that they do not use a drum nor pound upon anything in place of a drum. The Chocó, a neighboring tribe, use a drum but the musical customs and songs of the Chocó have not been adopted by the Tule. The statement of the Indians concerning the absence of a drum was corroborated by Major H. B. Johnson, formerly a lieutenant of the Black Watch, B. E. F., whose acquaintance with these Indians extends over a period of three years. Major Johnson went to Panama with a British expedition in 1921 and became particularly interested in the Tule; he was also a member of the Marsh-Darien expedition in 1924. He said that he had heard a great deal of their singing and was familiar with their use of other instruments, but had never known the Tule to use any instrument similar to a drum. Their only percussion instrument is the gourd rattle which, it appears, is used only in connection with flutes. Rhythms suggesting those played on a snare drum (*tat,* ra-ta-*tat,* ra-ta-*tat*-tat-*tat*) are played on the panpipes which are used to accompany dancing.

The musical instruments of the Tule are the panpipes, flute, gourd rattle, bone whistle, and conch horn. The flute and panpipes are easily made and the young men learn to play them chiefly by playing with the " official musicians " at weddings and other gatherings. The number of flutes played by the " official musicians " at a wedding is two, but any number of young men may play with them Gourd rattles are also used by the two principal musicians, and their music is limited to a sort of interlude played during the prolonged tones of the song.

The panpipes are the principal musical instrument of the Tule and are played for pleasure, as an accompaniment to dancing, and
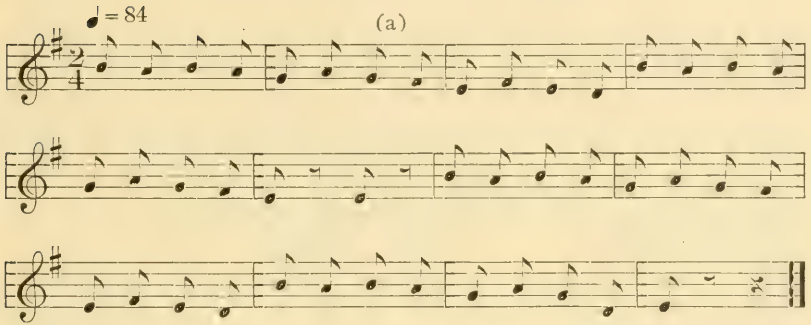
" for serenading the girls." Two series of reeds constitute a set, each series comprising three or four reeds of different lengths, bound together side by side and blown across the open ends. The two parts of the set are connected by a cord nine or more inches in length and the player holds one set in each hand, holding them with the ends having the shorter reeds next each other. Thus he has an instrument which produces high tones in the middle of its length and low tones at each end. In the sets contained in the Marsh Collection at the United States National Museum the shortest reed is $4\frac{1}{2}$ inches, and the longest is $14\frac{1}{2}$ inches in length. It is said that panpipes in the native villages frequently contain reeds 2 or 3 feet long, giving a deep resonant tone.

It is the custom of the Tule to play two sets of panpipes together, one player sounding one tone and the other the next tone, alternating throughout the performance. Igwa and Alfred Robinson (the interpreter) demonstrated this use of the instrument and produced a surprisingly loud tone resembling that of a calliope. It was said the instrument could also be played with a moderate tone. As Alfred was not an expert player, Igwa then played the instrument alone, giving a performance marked by a rapid succession of high and low tones, suggesting a performance on a concertina. Two expert players could, it was said, play the same sort of music in alternating tones. Another style of playing the panpipes was a sliding tone or *glissando* produced by passing the reeds rapidly in front of the player's lips, and yet another style consisted of rhythms on a single tone. Alfred said, " There are about 100 kinds of music played on the panpipes." The effect of this varied playing by skilled performers is undoubtedly very interesting.

Four sorts of playing on the panpipes were recorded and portions of the records transcribed. The same set of pipes was used in making all the records and the differences in pitch of the melodies are of special interest. The compass of the melodies is five tones (except for one tone in the first rendition), and the fourth tone of the compass does not occur. The intonation is fairly good, especially on the interval of a fifth. The melodies appear to be improvised along familiar melodic lines although each " sort of playing " is of an individual type. The first transcription is from a performance by two players sounding alternate tones, and the second, third and fourth are from a performance by Igwa alone.

MELODIES PLAYED ON PANPIPES
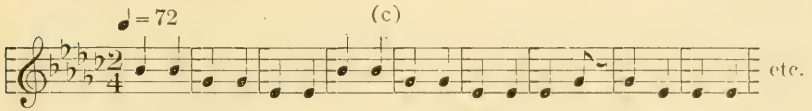
The Tule flute is "made of a different sort of reed" from that used in making the panpipes and all flutes are the same length. Such an instrument in the Marsh Collection is 24½ inches long and the two fingerholes are respectively 5 and 6 inches distant from the lower end. In making a flute the pith of a reed is removed with the stiff quill of a tail-feather of the wild turkey. The opening is flushed with water to remove all shreds of fiber, after which the fingerholes are burned with a hot iron and shaped with a sharp knife.

The manner of playing this flute is unique in that the end is held inside the player's mouth, apparently being placed near the roof of his mouth while the breath is directed across the open tube. It is believed this manner of playing the flute has not previously been described. When a gourd rattle is used with a flute, the player shakes the rattle with his right hand while holding the flute in position and manipulating the fingerholes with his left hand. The instrument is used thus at a wedding, two new flutes being made for the occasion. Before they are blown in the usual manner, the chief musician blows directly into the reed, "making soft little tunes." This was not demonstrated.

A flute performance by Igwa was recorded and the first portion was transcribed, the latter portion showing no important differences. Like the melodies played on the panpipes, this has a compass of five tones, omitting the fourth tone of the compass. It is minor in tonality and rhythmic in character.

MELODY PLAYED ON FLUTE
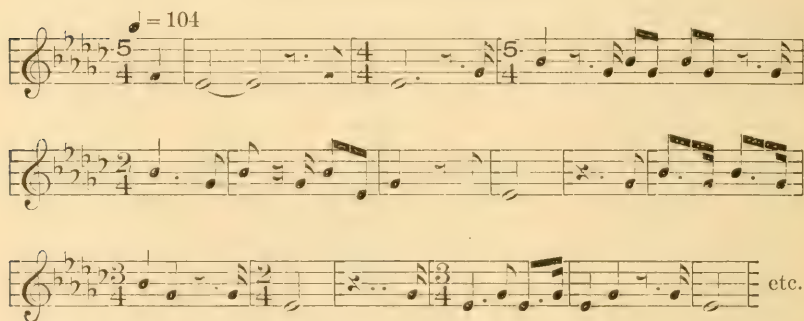
The flute, as stated, is often used with the gourd rattle, one instrument producing a melody and the other giving a rhythm, both being played by the same performer. The rattle is made of a globular gourd containing a few pebbles and pierced by a stick which

James Perry with conch horn.

forms a handle. The Tule instruments in the Marsh Collection differ from those of the North American Indians in that the gourd is fastened to the handle by a cord that passes through it.

The rattle used in connection with the flute is not large and contains rather heavy pebbles. The rattles used by the women are of two sorts, each being different from the rattle used with the flute. A woman's dance rattle contains many small pebbles and the handle passes entirely through the gourd. Sometimes the gourd is large and decorated with scrolls etched on its surface. The second type of rattle used by the women is about the same size as a man's rattle and contains many small pebbles and one rather large pebble. This is shaken " to put the babies to sleep," affording the only instance known to the writer in which instrumental music is used for this purpose. When the rattle is shaken the first resultant sound is that of the small pebbles, this is followed by the rolling of the larger stone which continues steadily and rather slowly, and has a peculiarly soothing effect.

The bone whistles are made of the wing bones of the pelican and " king buzzard." They have four fingerholes and are decorated with lines burned with a hot iron.

The conch horn (pl. 3) is made by piercing a mouthhole in the tip of the shell. The only variety of conch used in this manner is the *Casis cameo* Stem. A specimen of this variety shown them through the courtesy of Dr. Paul Bartsch, Curator of Mollusks, United States National Museum, was identified by the Tule as the type used by them. This instrument with its far-reaching tone appears to be used only as a signal. An informant said, " If a man has gone to another village and been away a long time he may blow this horn as he returns, to let his people know that he is coming."

TREATMENT OF THE SICK

The work of a Tule doctor is twofold as he ministers to both the bodies and minds of the people. He treats the sick by administering remedies and by such simple therapeutic measures as quiet and partial abstinence from food or drink, singing as he prepares and administers his most important remedies. In addition to this he teaches the young people, " beginning especially with the boys when they are very young. He exhorts them to right living, telling them not to quarrel, steal, nor tell lies." The Tule say that they have never been at war, and quarrelling among individuals seems particularly abhorrent to them. The doctor, chief and certain civic officials are

a " court of domestic relations " which reviews and adjusts complaints. If a wife brings a complaint, this court " scolds the husband," and if a man leaves his wife, the court forbids him to marry again.

Traditions exist concerning the power of the medicine men in former times. It was said that " the doctors used to dress up when they treated the sick, but they have not done this since Spain discovered the Indians." Such a doctor, when visiting the sick, would lay his rattle on the ground and it would rise to his hand, moving through the air. He would shake it and " in that way he would find out about the sickness of the patient." He could " bring animals into the house, so the people would hear the roaring of the mountain lions and the voices of other animals," he also had power to bring thunder, lightning, and rain, causing the rivers to overflow. It was said that the medicine men of long ago had power to sever a man's head from his body without touching him. A medicine man could stand near a tree and not look at it but " pray," and " pretty soon turn around and the tree was cut down as with a scythe." Alfred said his father has been told of this demonstration and has personally witnessed the severing of leaves from a tree in this manner. He has seen a doctor look at a young cocoanut, " pray," and the cocoanut fall to the ground. Inquiry was made as to what the interpreter meant by the word " pray." The reply was " Him not talk to anybody, him just *think*." To illustrate the action of the medicine man, Igwa placed both hands on his abdomen and appeared to begin an intense concentration of his mind. It is interesting to note this action, corresponding to the placing of the hand on the forehead, among members of the white race.

A Tule doctor of the present time pays for his knowledge of medicinal herbs and charges for his services, the fee being in proportion to the seriousness of the illness. Alfred Robinson said that his father is a doctor and " can tell what is the matter with a sick person by looking at him." In addition to his power to cure the sick he can foretell events, such as the coming of a " big fish " into the bay, he can forecast wind and rain, and locate lost or stolen articles. If asked to perform the latter service, he tells the man to wait until the next day for an answer, and the location of the missing article " comes to him in a dream." There is no singing in this connection. The father of Alfred Robinson also teaches young men who desire to be doctors and are acceptable for instruction. He can tell whether the young man has a good character, but nevertheless he questions

him concerning his parents and early life, asks his age, and whether
he has been fighting or has killed anyone. If he is not a good young
man, Alfred's father " does not try to teach him to be a doctor." A
person may be taught the use of one sort of medicine for about $10,
but it is considered better that a man begin when he is young and
learn the uses of all sorts of medicine. A fee of $100 is not unusual
for such a course of instruction and the required time may be ten
years. Formerly this man gathered the medicinal herbs which he
used, but at present the work is done for him by young men whom
he has instructed.

The father of Alfred Robinson receives his knowledge of medi-
cine from " little men " who appear to him in dreams. " The little
men come up out of the ground and talk with him, telling him how
to cure the sick. Some of the little men live under the ocean and
others live under high cliffs among the high mountains but they
usually come up through the ground." They were described as
being about 2 feet in height and resembling the Tule Indians in every
respect. No one except Alfred's father can see these little men.
The Tule said they did not know of any members of their tribe who
received help from birds or animals in their treatment of the sick.
It appears possible that the directions of the " little men " were con-
cerning the procedure in certain cases of illness, though they may
also have indicated certain plants as having a medicinal value. It
is not unusual for doctors among the North American Indians to
claim that they are under the tutelage of an unseen " helper " when
in the presence of a sick person. An image of one of the " little
men " is held by a Tule doctor when treating the sick, or he may
have it on the top of a cane which he carries. A bird is sometimes
on top of the little man's head " to help him." Such an image, used
by a doctor, is carved of wood and about 10 inches in height, and is
said to be the only representation of a " god " (or unseen helper)
which is made by the Tule. Examples of the images used by the
doctors and also the canes topped by carvings are contained in the
Marsh Collection. A carving similar to the doctor's, convenient in
size, may be carried in the pocket or placed in a trunk with personal
belongings to ensure the health of the owner and his family. Major
Johnson said that an Indian who had two of these images allowed
him to have one. The transfer was made in the morning. When
Major Johnson returned at night the man was waiting on the shore
and demanded the return of the image, saying he was afraid his wife
would be ill if he gave it away.

It is the belief of the Tule that almost every plant and tree has a good use. Vegetable poisons were known and used long ago but the chiefs have forbidden their use in recent years. A majority of the medicinal trees and plants grow along the rivers on the main land but some are found on the islands and a limited number of vegetable growths with medicinal value are found in the ocean. Leaves are never gathered green and then dried, but a doctor may gather leaves that have dried on the tree and keep them for a special use. He prepares his remedies in various ways and administers them both externally and internally. For a " weak medicine " he uses the water in which a vegetal substance has been boiled, but for a " strong medicine " he squeezes a liquid out of the substance after it has been boiled. Sometimes he pounds or mashes a root or bark and uses the resultant liquid.

Treatment by means of medicated baths is in favor among the Tule and is used especially for delirious persons. Alfred said that his father, like other doctors, has a small canoe on the land which he fills with water and uses for such treatments. The water is cooled by round, shining stones that he gathers " where a river starts." Some of these stones are white, others green, and they are always cool though the rocks around them may be hot. The healing bath used by Alfred's father is particularly interesting in the manner of its preparation. He takes two little strips about 9 inches long of the bark of the cocoanut tree, ties them in the form of a cross, and puts this in the water. The writer asked whether this form were not learned from a missionary and Alfred replied very positively, " Not missionary. Little man told him to do it that way." The patient bathes in this water three to five times a day, " according to how hot he is." The water is cooled by the stones and " cools him off," and he goes to bed between the treatments, drinking a medicinal potion. The place is kept as quiet as possible and the time required for a cure was said to vary from a few days to a month.

Infants are given strengthening as well as cooling baths. When an infant is five or six months old it is fed, occasionally, a little sweetened corn juice or water in which cocoa beans have been boiled. A little later it is given chicken broth and allowed to chew a stalk of sugar-cane. Its first solid food is potato or fish. The infant mortality is said to be low, and the general health of the people excellent. It is interesting to note that they avoid the flies and mosquitoes by living on the islands, and, as some of the islands are only a half mile from the shore, they can easily reach their farms and plantations on the main land, going there in the morning and returning at night.

The Tule, like some tribes of North American Indians, believe that the appearance of a plant is, in some instances, an indication of its medicinal quality. Thus the Tule chief sang concerning a vine that clings tightly to a tree, asking that the medicine made from this vine would "take hold of the disease as strongly as the vine takes hold of the tree." A somewhat similar example is afforded by the Tule remedy for hoarseness or cough. Water is poured over a set of panpipes and the patient required to drink it in order that his breathing may become as free as the current of air through the pipes.

The uses of certain herbs are commonly known among the Tule and they are prepared in a simple manner, but a doctor follows a different procedure with his "hardest medicines." He sings before gathering the plant in order to ensure its efficacy, and he gathers it in a prescribed manner. There is no "offering" made, corresponding to the tobacco placed in the ground by the Chippewa when about to gather medicinal herbs.

When gathering bark for medicinal use the Tule doctor cuts only four slices from each tree. First he cuts a small perpendicular slice from the east side of the tree, about 4 feet from the ground, and puts it in his basket, then he cuts similar pieces from the west, north, and south sides of the tree in this order, "talking all the time and saying that the medicine must cure people." If he wants more of this sort of bark he cuts it from another tree.

The following song is given as nearly as possible in the words of the interpreter, translating the dictaphone record, and the words fall naturally into the rhythmic form in which they are presented. The entire rendition was transcribed, comprising 292 measures. The melody is typical of Tule songs, and the time was steadily maintained during the prolonged tones and rests. The descending interval C-B flat has been considered on page 6. In this and in subsequent transcriptions, omitted measures are indicated by a break in the staff or by wavy lines.

NO. I. SONG BEFORE GATHERING MEDICINAL HERBS FOR THE
TREATMENT OF SICK CHILDREN

I go to look for medicine in the cool places where the rivers start,
I see the medicine that I want; it is a vine high up in a tree,
It will be strong, like the way it clings to the tree.
The fruit is blue clusters, cool like bunches of raindrops—
Cool as the rain falling gently.
O medicine, you must make the little children cool and you must not let them
    be sick again,
You must cool the houses of the sick children.
You will be used to bathe their little bodies.
O medicine, your name is *nugli, nugli, nugli,*
(I say it three times to make it strong.)
The thunder always falls from you, the lightning falls from you.
When they are far away they come to you and burn like a fire.
The thunder rolls, the rain falls, and the rivers overflow.
Rain clouds fall from you, that is why you are always cool.
Rain clouds come to your vines and tie up to them,
Rain comes to the *nugli, nugli, nugli.*
When you come to the child's house you must be cool and make everything
    cool like a cool rain,
You will go into the child's body and make him cool inside so he will get well,
    and you will make him strong,
You will not be alone when you come into the child's house.
A strong man-spirit watches to see the medicine work, and two spirit-girls
    will bathe the child.
The girl knows the child is sick by looking at it.
She is coming down the river to see the child.
When she enters the room it grows cool, even the clothing of the people is cool.
The man brings a cool fan,
The girl is bathing the child, you will bathe the child's body.

The last line is sung three times " to make it stronger." The singer
then addresses a second sort of medicine saying, " You come from
far up, where the river begins." This medicine is called *igiliwa ina,*
and the song, if given in full, would repeat the preceding portion
substituting this for the name of the first medicine. The song then
mentions a third medicine called *inakaryaka tuba* in a similar man-
ner. All three are vines and they were combined in a medicine that
was used for children both externally and internally.

Songs were sung during the treatment of the sick, only one of
these being recorded. The statement that " the Tule have doctors
for snake bite as well as for headache " suggests that their doctors
are specialists, as among the Indians of North America, but the
writer's notes do not contain a definite statement to that effect.

NO. 2.   SONG WITH TREATMENT OF HEADACHE

The transcription of this song comprised more than 200 measures. The portion presented is typical of the entire melody except for occasional measures that begin with a strong accent. The tone A sharp is substituted for A natural in the latter part of the song, changing it from minor to major in tonality.

<center>(The doctor speaks)</center>

I bring sweet-smelling flowers and put them in water,
I dip a cloth in water and put it around your head,
Then I bring a comb, part your hair and make it pretty.

<center>(The sick man speaks)</center>

You are a good doctor, everyone knows you.
You will make me better.

<center>(The doctor speaks)</center>

Everyone comes to see you get better,
And I tell you that you will never feel cold again.
Go to sleep and dream of many animals—mountain lions and sea lions,
You will talk with them and understand what they say,
And when you wake you will be a doctor like me.

NO. 3.   SONG AFTER A MAN DIES

The Tule are a people of strong affections, and a death is followed by great sorrow. A man's valuable belongings are not buried with him nor destroyed, as is customary among certain tribes of North American Indians. His name is never spoken after his death, a cus-

tom which the writer noted among the Yuma and Cocopa of southern Arizona. It was said that "after a death the people go to the burying ground, take their lunch and stay all day. The doctor sings and talks about the dead person and everybody cries." The songs used at this time recount the circumstances of the man's illness and death, and "direct his spirit on its way." Such a song is presented, and we note that the tempo is more rapid than that of any other recorded Tule song. Only the first part of the words was translated, the second portion evidently containing a native adaptation of ideas obtained from missionaries. The translation was made from the dictaphone record, phrase by phrase, as described in the song of the boat race on page 29, but the phrases in the melody are not strongly marked and the corresponding numbers were not placed on the transcription. The song is characterized by its rapid tempo and by frequent repetitions of a single tone.

(The sick man addresses his wife)

The fever returns. I drink the medicine and throw it on my body.
The sickness comes more and more. I am going to die.
My breath grows harder. I am going to die.
My face grows pale, the medicine is not helping me.
I am going to leave my two children to you,
After I die you will feel sorry for them.
After I die you must always talk of me to the children.
Go to the cocoanut farm after I die,
Take the children with you and be sad for me.
If people go into the cocoanut farm and cut the trees
Track them and find out who did it.
Always think of me when you go to the cocoanut farm.
There will be plenty of property for the children.
I will leave the plantain farm.
Always think of me when you go to the plantain farm.
I leave the small fruits, the bananas, mangoes and other fruits,
When you pick them you must think of me.
Before I was sick I went fishing and caught fish for the children,
I cannot get you any more fish.
Before I was sick I went hunting and got birds, wild turkey and all kinds of
    game,
After I am dead I cannot do this any more,
Think of me when you eat the wild game.
I always killed the wild hog, I always killed the wild turkey,
I asked everybody to the big feast, but I cannot do this any more,
I am going to die now, I cannot talk.
My breath goes, I speak faintly.
You must remember me a *little* bit.
In a little while you will forget me,

Perhaps three days after I die there will be a big party,
I believe you will paint your face, dress up and not think of me,
You will begin to love some other Indian.
There will be many Indian boys for you,
But I will learn many new things where I am going.

(The man then dies, and the remainder of the song is concerning the journey of his spirit.)

WEDDING CUSTOMS

The principal social event among the Tule is a wedding, with its accompanying festivities. The people assemble from neighboring islands and dance and sing for several days, according to the wealth of the bride's father who provides the entertainment.

A young girl is not left without advice in choosing a husband. Her father notices that a certain young man is a good hunter or fisher, that he is an active worker in the fields, or that his father is a rich man having many cocoanut trees. He calls the girl's attention to this circumstance and she regards the young man with favor. It is customary for the father of the girl to propose an alliance, visiting the young man's father for that purpose. A knowledge of this custom was obtained in the following manner. While the study of Tule music was in progress a gentleman was invited to hear the Indians sing. There was some consultation and then, without explanation, Igwa began to sing and dance, advancing toward the gentleman. Approaching the gentleman who (unwittingly) represented the girl's father he stroked and patted his knees in an ingratiating manner, as a white man might pat another on the shoulder. First the left knee and then the right was treated in this manner. Igwa, who had been standing in front of the gentleman, then danced around him several times. When the action and song were concluded it was said he had shown how a Tule father asks that a man's son shall marry his daughter. The melody was not recorded. It is probable that the words were similar in character to those of the wedding song.

The father of a Tule girl begins to gather presents for her wedding while she is still a small child. Tule girls usually marry when they are about fourteen years of age and by that time the father, if he be a man of property, has a good supply of presents. The parents of the boy also give generous gifts if they can afford it.

The song which is sung at a wedding contains a narrative of the entire event, given in the present tense and beginning with the gathering of presents by the girl's father. It is the writer's custom, in

Drawing by Igwa Nigdibippi.

studying Indian music, to have the words of a song translated from the phonograph record of the song, but in this instance a different method was followed. The wedding customs were described before the song was recorded, and when the interpreter was asked for a translation of the dictaphone record he said: "Him sang just what we *told* you. Him sang how the father gets the presents ready, the chief tells the people, the chief musician makes a new flute to play at the wedding and everybody sings and dances at the wedding. He *sings* that in the *song*." A general translation of the words showed they were, as the interpreter said, an account of the festivity but condensed so that the record of the song would not be too long. The description already given was therefore paraphrased and read to the Indians who added some details and adjusted the sequence of minor events where correction was necessary.

The manner of playing the flute at a wedding was demonstrated by Igwa and Alfred Robinson, representing the chief musician and his assistant. They pointed the flutes upward as though they were trumpets, then bent low and went through the actions which are associated with players of "jazz." They jumped upward with both feet and came down facing in the opposite direction, then reversed the action. The musicians wore feather head-dresses, the feathers being fastened erect in a band around the head. An example of this ornament is in the Marsh Collection. Two scenes at a wedding are shown in a drawing made by Igwa when in Washington (pl. 4). The purpose of the drawing was a map of the region in which his people live and the drawing was made on a large white cloth. After completing the shore line and its adjacent islands, the open space of the ocean attracted his attention and he drew, in the center, a picture of the chief musician and his assistant playing the flute and rattle at a wedding, surrounded by a circle of people. At the left may be seen the bringing of a pole for the house of the young couple, as described at the close of the wedding song. At the top of the picture is the name of the present chief, Golman, and the name of Igwa in the neat printing which he learned while in the United States.

The words of the wedding song mention the burning of cocoa beans in front of the musicians to protect them from harm. These were placed in little braziers with openwork tops, raised above the ground a few inches by supports, examples of these being in the Marsh Collection. The "man in charge of the stoves" carries coals on a long spade from a large fire and replenishes the fire in the

braziers; he also stirs the cocoa beans and adds more when neces-
sary. A similar custom was observed among the Papago Indians,
who live in southern Arizona, and in northwestern Mexico.

The beverage designated as " chee-sa " is drunk at all social gather-
ings of the Tule, and one man in each part of the country is expert
in its preparation. It was said that " in old times chee-sa was drunk
during the bringing of rain by the medicine man." Banana juice
forms the principal ingredient. This is boiled, then sugar-cane juice is
added and it is boiled again. A little corn juice is put in and the liquid
allowed to stand in sealed jars from six to eleven days. A reasonable
amount of the beverage was said to be stimulating, but those who
drank to excess were intoxicated by it. In this connection it is
interesting to note that a native wine made from the fruit of the
sahauro cactus was ceremonially prepared and drunk by the Papago
Indians during their ceremony to bring rain.

NO. 4.   WEDDING SONG
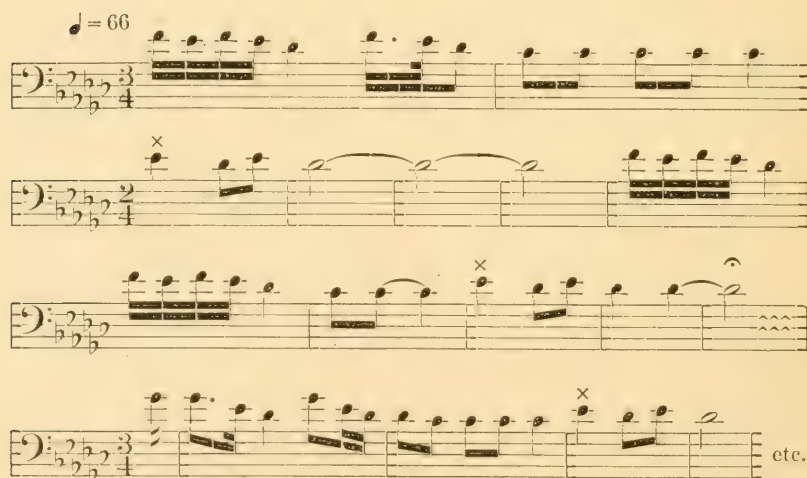
The melody of the wedding song has more motion than the other
Tule songs although the tempo is not rapid. The song is char-
acterized by a recurrent phrase (marked ✕) which seems to imply
a question and is not entirely happy. The apparent keynote is the
highest in the compass, which is unusual in Indian songs. The wavy
lines indicate the omission of measures (see page 5).

(The father of the bride speaks)

I buy the wedding gifts for you, my daughter,
And add them to the store that I have saved for many years,
Preparing for this feast.
I buy silver spoons, large and small, from Panama City,
Steel knives and small, sharp pocket-knives,
Scissors and blankets, silk shawls, and kerchiefs for the head,
All these must come from Panama,
With dresses of pretty colors and strings of beads,
Strings of silver money, and a string of gold beads that I will put over your
    head,
Earrings of gold, bracelets and anklets of bright colored beads
And narrow combs, such as our women use.
Cups made of gourds I may buy from our neighbors,
And ladles of gourd with long wooden handles.
Your mother will make hammocks for you,
Gathering the cotton, spinning the cord, and weaving them for her daughter.
Your cousins are even now making baskets for the wedding cakes and fans for
    our guests,
Your brothers will bring fish and game for the feast,
We are collecting jugs to hold the chee-sa,
There will be enough for all to drink.

Now I will go to the chief and tell him we are ready for the wedding.
He invites the villages, sending his canoes across the bay.
The young men will make flutes to play at your wedding,
Flutes of cane and panpipes made of reeds.
I ask the chief musician and he brings his assistant.
I choose the men who make the chee-sa, carry the water and prepare the feast,
They also tend the little fires in which we burn cocoa bean,
Putting one burner before each musician the first day,
Two the second, three the third, and four the fourth, according to our custom,
So that no harm will come to them from playing.
Bring the kettles for making the chee-sa,
Put them in a row over the long fire,
Mix the banana juice, sugar-cane juice and corn juice,
Watch it boiling until the taster says it is ready to put in the jugs,
Seal the jugs and cover them with leaves.
Now let the leader sing, if he knows the songs that make good chee-sa,
Night and day he and his helpers must stay near the jugs,
If the taster is not satisfied the mixture must be corrected.
After a few days the leader says that the chee-sa is ready.

Now we will have the wedding feast.
The morning sun is halfway up the sky,
Come! it is time for the wedding.
The chief musician and his assistant are in their places.
Four men trot across the room and blow smoke on the two musicians,
Smoke from a great cigar of our tobacco, rolled one leaf upon another,

Protecting those who will play the flute and rattle on your wedding day.
Now they will make the new flutes.
The assistant musician cut the canes beside a mountain stream
And sang, so that the flute would make sweet music for your wedding.
He stands beside the chief musician and each holds an unfinished flute,
Two men go toward them, trotting across the room,
In their hands they carry hot irons with sharp points.
Now they are burning finger holes in the new flutes,
Twice they go forward and touch the canes with their hot irons,
Then the finger holes are shaped with a sharp knife.
See them blow straight through the flutes without touching the finger holes.
Then each takes a gourd rattle and shakes it.
The chief musician plays the first tune at your wedding,
Afterward the helper plays with him and all the young men may join the music,
Playing the flutes they have made for your wedding.
Watch the chief musician and his helper.
Suddenly they turn, facing in opposite directions,
Then stand side by side again
And bend over so that the flutes almost touch the ground.
Now the men and women stand in a circle, the musicians in the middle,
They dance sideways, facing inward,
Suddenly the leader gives a signal and they face outward,
Moving sideways in a circle as before.
Sometimes they move in a line, each with hands on the hips or shoulders of
    the person in front.
All the people wear their prettiest clothes
When they dance at your wedding.

The sun has passed the half of the sky,
'Tis time for the feast in the little wedding house where we are assembled,
Bring the fish and game, the cakes and cocoanuts,
Bring the flat baskets heaped with fruit.
See! The chee-sa will be offered first to the chief musician,
He will drink a large cup for the boy, then a little cup for the little bride,
Now the man appointed is standing with the cup of chee-sa,
He holds it up and says, " Watch, O musician, I am going to bring you chee-sa."
Then he crosses the room and hands the cup to the musician.
See! He holds it up and says, " Watch me. I am going to drink the chee-sa."
Happy are the boy and girl when the chief musician drinks to them.
Chee-sa is served to all the guests by men appointed for this work.
In the late afternoon we bathe in the ocean,
Bathe as the water is red and gold with sunset,
Then with fresh clothing we go to the dance.

It is evening and the guests are in the big wedding house,
Blazing torches made of nuts are along the walls,
And bright lights made of cloth dipped in honey,
While from the roof are hanging lanterns brought from Panama.
The men are on one side of the room and the women on the other.
I escort the chief musician into the house of music,
I take him by the arm as though he did not know the way, and seat him in
    his place.

The young boys play their flutes as we come in,
Everyone claps their hands as I escort the chief musician at my daughter's
    wedding.
In a similar manner my wife escorts our daughter into the house of music,
And with them comes the woman who will cut her hair.
· All night the young people may dance if they like,
The managers of the feast, both men and women, will remain in the house,
While across the water move the canoes of those who wish to go home and
    sleep.

Early in the morning begins the cutting of the bride's hair—
So early that the sky is scarcely red in the east.
The haircutter may know many songs to sing, or she may encourage others to
    sing as she works.
The little bride is seated between her mother and her grandmother,
Behind her stands the haircutter with sharp scissors,
In front of her sits the assistant haircutter.
Chee-sa is brought. Four times the assistant hands a tiny cup of it to the
    haircutter ;
Then four times the haircutter hands a tiny cup of it to her assistant.
All around are the young girls and women singing pretty songs to the bride.
They sing, " Your husband will be kind to you " ; and " You will have a nice
    home."
They dance alone or in little groups, clapping their hands as they sing.
Now the haircutter parts the girl's hair from her forehead to the back of her
    neck,
Then parts it across the top of her head from ear to ear.
Slowly she snips a few hairs at a time until all is made short,
The cutting of the hair will take until noon,
With the young girls dancing, clapping their hands and singing about the kind
    husband and the happy home.
The girl will take the packet of hair to her new house,
She will tie it up close to the rafters.
Sometimes she will look up and see it there,
When she has lived a long time in that house.
The hair cutting is finished and a bright kerchief is tied on the girl's head,
She puts on her prettiest dress, reddens her cheeks and paints a red line down
    her nose,
Strings of silver money, glass beads and gold beads are around her neck.
See her earrings, anklets, and bracelets.
Now she dances a little with the assistant musician,
The haircutter also dances a little with the assistant musician,
And all is ready for the second feast.

Bring the coffee ! Bring the deer meat, fish, and wild turkey,
Bring the cakes her mother made of cocoanut, corn, and honey.
There are dishes for all, and the choicest food for the special guests.
Great kettles of soup are ready for those who came because they heard there
    was to be a wedding,
The people from distant islands and the young men who boast they never have
    missed a wedding,

Let everyone be happy.
The bride sees a speck of dust on her dress.
Quick, bring another! She may change her dress every hour—blue and orange,
    white and pink.
Other brides may wear one dress for all the days of their wedding
But my daughter may change as often as she likes,
She may wear new shawls, new dresses and new kerchiefs of silk.
The young girls bathe in the ocean three or four times a day,
Then lie down and rest, put on fresh dresses and dance again,
The young men do the same, putting on fresh finery to please the girls.
The music is always playing in the big wedding house,
And all may dance as they wish, by day or night.
Three, four, or five days the dancing and feasting may continue,
With plenty of fruit and cakes and chee-sa for everyone.

After the feasting, the singing and dancing are finished,
After the distant guests have gone away in their canoes
The friends of the boy will help him make his house.
His brothers will help cut and carry the main poles
And all his friends will put on the thatch,
Then there will be another feast. If he has killed some game
The bride will cook it for their guests.
The chief will sing at the feast, giving good advice,
Telling the boy that he must work hard and the girl that she must keep her
    house and dishes clean.
Three days they will feast and sing,
Then they will go away in their canoes across the water.
The little bride will arrange her cups and other things
And the boy will go to gather cocoanuts and sell them,
He will try to gather many and sell them to a sailing boat from Panama City.

TURTLE CATCHING

At the season for catching turtles the men prepare a certain
" charm " to attract the turtles. It is not the custom to kill a turtle
but to catch it, remove the shell, and put it back in the water. It is
said " If a man kills a turtle he never can catch another, but if he
treats the turtles right he can go every day and get two turtles." In
the proper season a man can work a month and secure about 50
turtles, removing the shells which have a commercial value.

The following song was sung during the preparation of the charm
for catching turtles, in order to make the charm effective. As in
other Tule songs, the words relate a succession of events. In the
music with the portion of the words marked (A), the third is some-
times a minor and sometimes a major third above the keynote, but
in the latter portion, marked (B), the third is always major and
the melody is particularly lively. Between these parts of the song
there are three measures in a slower tempo.

The transcription of this song extends from the beginning to the end of the dictaphone cylinder and comprises more than 100 measures, but omits the uninteresting portions of the melody. The song opens with an introductory phrase similar to that in other Tule songs. This is followed by a melody in what might be termed a " descriptive form," somewhat resembling that of the song connected with the gathering of medicinal herbs. The portion of the transcription here presented begins with the slow measures which occur between the two parts of the song. We note with interest the return to a more rapid tempo, and the sixteenth notes followed by rests occurring in the part of the song which mentions the attracting of the turtle.

NO. 5.   SONG CONNECTED WITH CHARM FOR CATCHING TURTLES
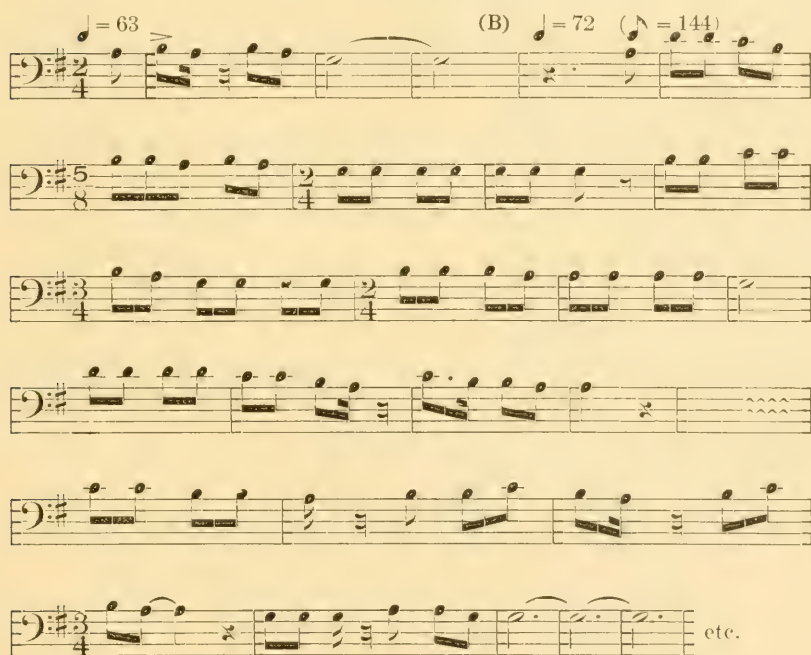
(A)   I am going to shoot a little bird,
    Sarwiwisopi, that can tame the turtle,
    Now I bring it home and hide it,
    Then put it in a little clay stove until it burns to ashes;
    I am mixing the ashes with red medicine,
    From the juice of a certain tree I make this medicine;
    I am cutting a little round gourd in two, cutting off the top very neatly,

With my knife I scrape the inside of the gourd,
Scrape it smooth and clean like a cup;
I put the medicine into this cup—
Ashes of the little bird and red tree-juice,
Now I tie the cover on tightly,
Put it in my trunk and tell nobody.

Every night for eight nights I take the gourd out of my trunk,
The smooth round gourd, with top tied on so tightly,
I put cocoa beans on a little fire and smoke the gourd,
Singing this song while the smoke curls around it—
    " Little bird, I saw you
        And I knew you would be a good bird to catch a turtle,
        That is why I shot you.
        Now if you do not tame the turtle
        Everyone will say you are not a good bird,
        But I know you will tame the turtle,
        Then I will make lots of money
        To buy a gun, a shirt, and many things I like."
After the eighth night of singing my partner comes,
We go down to my canoe,
I put the gourd carefully in the middle of the canoe,
I have a long pole, a spearhead and a line,
The spearhead will be fastened on the pole
And with it I will spear the turtle.

(B)   Now I am talking to the medicine in the gourd and saying,
        " When we get out to the ocean
        I will send you down under the water,
        I will send you down to attract the turtle,
        When you get to the bottom of the water
        You must put on your pretty blue dress
        So the turtle will come to you.
        Change your dress many times,
        If the turtle has on a yellow dress
        You must put on a yellow dress,
        If the turtle has on a white dress
        You must put on a white dress,
        If the turtle has on a blue dress
        You must put on a blue dress,
        You must do this to attract him.
        When you get the turtle
        Bring him up to the canoe and I will spear him.
        Tell the turtle that the man who sent you is not going to kill him,
        Tell the turtle I will only take off his shell and send him back where
            he came from,
        So you will catch many turtles for me,
        And everyone will say you are a good bird."

MISCELLANEOUS SONGS

The four songs next following were sung by the "official musicians" for the entertainment of the people at their social gatherings. One man sang alone and six men stood in a line and played flutes during the prolonged tones that occur at regular intervals in these melodies. The people were "all dressed up pretty." They "sat around and drank chee-sa."

NO. 6.   THE BOAT RACE

The native boat used by the Tule is a dugout made of the trunk of a tree and varying in size from a small boat carrying two or three persons to a long, wide boat carrying about 15 men. The latter is the size in common use and is equipped with one mast, one sail and a jib. It is never paddled if there is enough wind for sailing. Boat-racing is a favorite pastime of the people and a race usually begins about six o'clock in the morning, ending about noon.

Two renditions of this song were recorded, the second being about a week after the first. Transcription is from the first rendition. In obtaining the translation of this rendition the dictaphone record was played for a few seconds and that portion of the words translated with a notation of the numbers on the dictaphone space bar. Thus the third line of the poem occurs between numbers 3 and 7, and the fourth line between numbers 8 and 10 on the space bar. Corresponding numbers were placed on the transcription, making it possible to connect the words with the music to which they were sung. The portion of the transcription herewith presented consists of the introduction and three phrases, each with a dictaphone space number. A comparison of the translation and transcription at these points is of interest. After these phrases the melody contains many repetitions of single tones and is lacking in musical interest. The remainder of the poem is a combination of the two translations, some details of the race being given with the second rendition which were covered by a general statement when the song was first recorded.

(2) Two boats are going to race. There are many men in each.
   Those who steer the boats wear wide hats. When the wind blows it flaps the hats.
   One boat moves very fast and sways with the waves;
   It stops a few moments at a town but no one gets out.
(20) The wind rises. A heavy sea begins.
   Now the boats have all begun to take down their sails.
   The wind blows harder and harder,
   The waves dash over the boat and the men cannot stand up.
   The sailors go to the tops of the masts and jump from one mast to another like monkeys,
   The sailors' wives are frightened as they watch from the shore.
(30) The wind grows stronger and stronger.
   The captain says he had thought they could reach the next town but now he is frightened.
(32) He tells the sailors to take down the sails quick, quick.
   The owner says, " This is not your boat. The sails are not to come down."
   The owner of the boat says, " I do not think the wind blows hard. I want *more* wind."
   The boat leaps from the top of one wave to the top of the next like a flying fish,
   It passes another boat, leaving it like a log on the water.
   The captain calls to the captain of that boat, saying,
   " I thought we were going fast but when I look at your boat I see we are not going fast at all."
   There are many flags at the top of the mast,
   They make a soft noise like bright birds.

The sound of the ropes whistling in the wind is like the sound of many birds,

The blocks tick together like the ticking of a watch.

On the shore the girls are watching. They jump and wave their hands, excited to see who will win.

The wind blows harder and harder. The boat heels over so the keel can be seen.

The bowsprit shakes and trembles, and the water barrels go overboard.

Now the boat is filling with water.

The captain is a negro with thick lips and a wide hat, and his hat flaps.

He says, " Cut down the mast. The wind comes harder every minute."

The owner of the boat sits down in the cabin.

He reads in a prophecy-paper that the boat will be lost.

Now the wind has died down.

The owner says, " That was why I did not want the sails taken down. I knew there would be a calm."

Then the wind comes gently and they go home.

It was early morning when they started and now it is noon.

The captain who won the race steps ashore and sees a pretty girl.

He says, " You were a little girl the first time I saw you. Now I want to marry you."

All the sailors shake hands with the captain and the girl.

Now she will not speak to the boys any more.

There is a party and everyone drinks chee-sa,

Everyone dances at the wedding of the captain and the girl.

NO. 7.   SEEN THROUGH A SPYGLASS

A conversation between a boy and two girls is recounted in this song. The name of the boy is Nigalili, the older girl is Sianili and the younger is Wagayokili; the boy and older girl are " doctors " (possessors of mysterious power). They are sitting in a house and looking toward the sea through a spyglass. It was said the Tule had seen spyglasses but did not own one. The principal characteristic of the melody is the downward sequence of three or four consecutive tones.

(The older girl speaks)

You cannot see mountains and valleys in the clouds,
I see the clouds as big trees,
When I look far away the clouds are like cliffs of high, gray rocks.
I see a cloud that looks like a cocoanut tree.
The clouds come up and come up in different shapes.
There are clouds that look like breakers,
You do not see the colors and shapes of the clouds,
I see them like people moving and bending, they come up like people.
There are clouds like many people walking.
I see them every time I look out to sea with the glass.
Sometimes a cloud comes up like a ghost, and sometimes like a ship.
I look through the glass far away and see everything.
I see a cloud that looks like a sea horse, a wild sea horse that lives in the water;
I see a cloud like a deer with branching horns.

(The boy speaks)

You do not see that.

(The older girl speaks)

From the time I was a child I did not think I would see such things as these.
If I do not look through the glass I cannot see them.
Now I find out the different things that the clouds make,
Do you want to see them too?

(The boy speaks)

All right. I want to see them too. (He looks through the glass.)

(The boy speaks)

Now I see funny things.

(The girl speaks)

You see all those funny things.

(The boy addresses the younger girl)

Do you want to see too?

(The younger girl speaks)

No. I am too young.

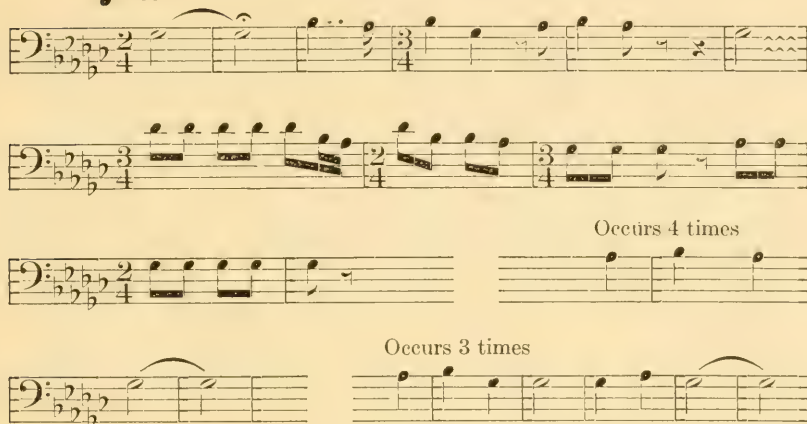(The boy addresses the older girl)

Look down into the water with the glass.

(The older girl speaks)

Now I see strange things under the water.
I see things moving around as though they were live animals,
I see things that look like little bugs, and many strange animals under the sea.

NO. 8.   WHERE THE RIVER BEGINS

This was said to be a very humorous song, and the statement that the salt water barrel came to see the fresh water barrel was greeted with much laughter on the part of the Tule who heard the song recorded. Tule songs are not characterized by units of rhythm but this song contains two phrases which were repeated several times, the repetitions probably occurring with the statement that if something should loose its hold the water would flow out of the barrel. Only a few phrases of the transcription are presented, and the words are condensed.

At the top of the river there is a big barrel, four fathoms around,
It is full of water and there are eight plugs in its side.
A waterbird sits on the barrel,
It is a pretty bird with feathers like pink and red roses and bright blue flowers.
The waterbird holds one of the eight plugs,
If it should let go, the water would flow over everything.
A little round shell is holding one of the plugs,
If it should let go, the water would flow over everything.
One of the plugs is held by a little flat fish that lives in the sun, under the rocks of the river,
    If it should let go its hold the water would flow over everything.
A long slippery eel holds one of the plugs,
If it should let go its hold the water would flow over everything.
A brown crab holds one of the plugs,
If it should let go, the water would flow over everything,
A river crab holds one of the plugs,
If it should let go, the water would flow over everything,
A little river fish holds one of the plugs,
If it should let go, the water would flow over everything,
A very small crawfish holds one of the plugs,

If it should let go, the water would flow over everything,
These eight hold back the water.
The big barrel lies on the ground,
All the little streams from the mountains come to the top of it.
The salt water barrel comes to see the fresh water barrel,
Many big animals from the mountains come to see the fresh water barrel,
The little streams from the mountains come to see the fresh water barrel.

NO. 9.   LOVE SONG
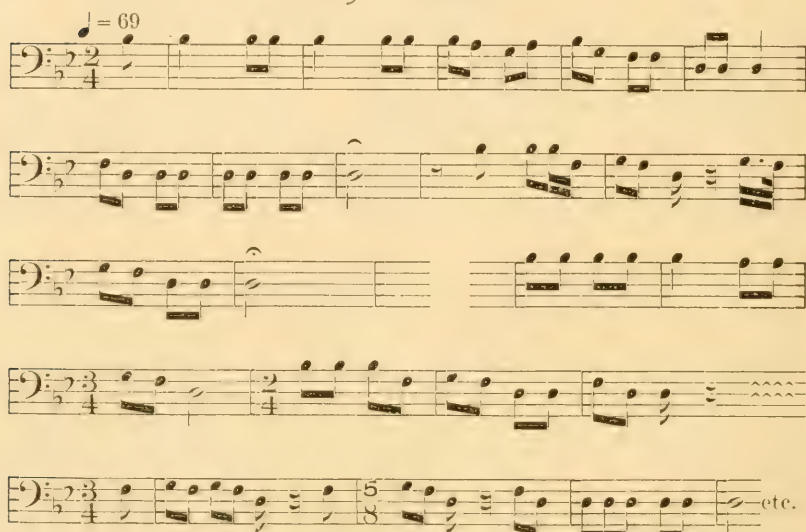
The rendition of this song covered almost two cylinders and was about 15 minutes in duration. In the first portion the keynote was the highest and most prominent tone, but in the middle and latter portions the lowest tone of the compass was the most prominent. The opening phrase and a characteristic phrase from the latter portion are here presented, with a portion of the words.

Many pretty flowers, red, blue and yellow,
We say to the girls, " Let us go and walk among the flowers."
The wind comes and sways the flowers,
The girls are like that when they dance,
Some are wide-open, large flowers and some are tiny little flowers.
The birds love the sunshine and the starlight.
The flowers smell sweet,
The girls are sweeter than the flowers.
I go among the girls and see them all,
But I like only the one I walked with first,
My eyes are open for her but I look at the others as though I were dreaming,
I say to her, " When I die you must think of me all the time."
I look at the others as though I were dreaming,
The girl is dreaming too.

NOTES ON TULE CUSTOMS

FOOD

The fruits gathered by the Tule include cocoanuts, oranges, pine-apples, mangoes, and certain varieties of alligator pear, but they have no edible berries. On their farms they cultivate corn, sugar-cane, cassava, and plantain as well as sweet potato, pumpkin, and other vegetables. Beans are used very little. Many sorts of pepper are raised, the people being particularly fond of red pepper. Scare-crows are erected to protect growing crops. Corn is eaten when green, or allowed to ripen and put in little storehouses near the field, or it may be taken across to the islands and stored there. The owner often makes a little fire under the storehouse to keep the corn dry, and he watches that animals do not molest it.

At present the corn is ground in a handmill purchased in Panama City, and the cornmeal is made into bread. A favorite delicacy is made of cornmeal and grated cocoanut, sweetened with sugar-cane juice, shaped into a long loaf and baked on top of the stove. "Sugar-plums" are made of cornmeal and sugar-cane juice boiled all day so it becomes very thick. Similar confections as well as sirup are made of sugar-cane juice, boiled a long time.

The game consists of deer and wild pigeon, turkey and other birds. Meat is never dried. If a man kills some game he eats it for one or two meals and gives the remainder to relatives and friends or invites them to a feast. The meat is all eaten in one day. For a long time they have had domestic fowl, including chickens, ducks, tame pigeons, and occasionally turkeys. Pigs are also kept and eaten.

From the Caribbean Sea the Tule obtain crabs and lobsters, and from streams and rivers on the main land they obtain fresh water lobsters, as well as trout, smelt, and other fish. They never take home the fish caught in the small streams, but fish from the rivers are taken to the islands and prepared in various ways. Fish may be boiled in fresh cocoanut milk. The women boil cocoanut milk, skim off the oil that rises to the top and put it away in a bottle for use in frying fish. If the Indians wish to keep fish they score it with a knife, rub it with salt and dry it on a slat frame over an open fire. A few hours is sufficient for the drying of fish.

The principal beverages are coffee and an infusion of the cocoa bean. Infusions of various leaves are also used including the leaves of orange trees and a fragrant leaf called "fever grass." Plantain juice, boiled and sweetened, is used as a drink. Another favorite drink consists of sugar-cane juice boiled a long time, after which a tiny bit of corn is added. This drink takes so long to prepare that

it must be started about three o'clock in the morning in order to be ready for use at eight or nine o'clock.

The making of chee-sa, the principal drink of the Tule, has been described in connection with the wedding customs.

HOME LIFE

Women never work in the fields.

There is no ceremony nor feast connected with the naming of a child.

The instruction of a child is begun by its mother before it can understand her words.

The Tule mother sings her baby to sleep, saying its father has gone planting or harvesting the crops. If the baby is a boy, she sings that when he grows up he must be a good worker in the fields. If the baby is a girl, she sings that she must work diligently at home when she grows up.

Red paint is made of the juice of a certain plant and with this the women draw a narrow line down the top of the nose and slightly redden the cheeks. The women's hair is short and cut squarely across. In former times the Tule women wore clothing made from the bark of certain trees, pounded until only the fiber remained. Their present costume consists of a tunic made of calico or gingham decorated with applique designs of similar material in a contrasting color, this work being done very neatly and in elaborate patterns. The skirt consists of about 2 yards of calico or gingham wrapped around the body and held in place by tucking in the upper corners at the waist line. This is worn over the tunic, forming a garment that is very tight around the hips and loose at the knees. With it is worn a loose head covering of cloth that protects the head without additional heat (pl. 5). The men wear the ordinary clothing of civilization. Nose-rings are worn at the present time by the women, and large discs of gold are often fastened to the ears. Necklaces are favorite ornaments among both men and women, the men wearing strings of the teeth of the mountain lion and the women wearing strings of monkey teeth. Fragrant berries are dried, strung, and worn by the women. Strings of silver coins are also worn as necklaces by the women.

MANNER OF LIFE

The Tule live in compact villages—there are no scattered houses. The islands on which they live are, in some instances, only half a mile from the main land. A man's wealth consists of land and trees,

Alice Perry in native costume.

the cocoanut trees being most valuable. Fruit is sold to sailing vessels that come from Panama, varying in size from little boats with one mast and two jibs to sloops and schooners. Payment is sometimes made in money but usually in cloth and commodities which are of very inferior quality. These boats afford the only communication between the Tule and the outer world. There are no stores in the region except a very few small stores kept by Indians or Spaniards. Bananas bring only the equivalent of five or ten cents a bunch and the people do not consider it worth while to sell them. Cocoanuts bring the equivalent of about $12.50 per thousand. The cocoanut trees in the jungle are too old to bear and it is necessary for a man to clear the land and plant young trees. The men are industrious and are usually at work on the farms at six in the morning. In the busy season they work from three in the morning until about five in the afternoon.

OFFICE OF THE CHIEF

The office of chief is held for life and is not hereditary, though the son of a chief may be elected in his father's place if he has the requisite ability. After a chief dies, the people meet and discuss a possible successor but a vote is not taken until the opinion is unanimous. Then someone says (in effect) "So-and-so is a good man, let us make him chief," and all the people give their assent. It is said that a dissenting vote has never been known.

One of the duties of a chief is the instruction of the people in ethics. It was said, " The chief holds a meeting almost every night and talks. Him tell people must not quarrel nor say bad words. God say people must not do such things." If they do not have a good crop the chief says, " It is because you have been telling lies and talking badly. You cannot have good crops if you do such things." He also exhorts the people to work hard in the fields.

Inquiry was made as to certain Tule beliefs and the reply was that good people, after death, " go up in the sky, walk among gold and silver flowers and along golden streets." The inquiry was then discontinued. At a subsequent time the writer asked whether the Tule have any belief concerning a bridge that is crossed by the spirits and Igwa replied without hesitation that the spirit makes the bridge *himself*. He said the spirit, after death, comes to a big lake, he tosses a string into the air and it falls on the opposite shore of the lake, becoming a bridge which he crosses. Igwa said further that a man, after death, goes under the ground and there sees golden

rocks and golden trees. He gets into a boat on a big river and the boat " goes as fast as lightning " without any effort on his part. It is interesting to note the presence of both native and acquired ideas in the minds of the Tule.

When asked concerning the origin of the Tule, Igwa said that long ago 40 or 60 Tule Indians came down from the sky and that " one of them knew everything."

The informants said that all the Tule Indians know that the earth is round and revolves once a day, this revolution making the sun appear to be standing still.

It was said that the Tule have five " gods," only the " god of health " being represented by an image. The others are those of harvest, rain, fishing, and hunting. No further inquiry was made concerning the latter, but the " god of health " is mentioned in connection with the treatment of the sick.

GAMES

The Tule do not sing to bring success in games or contests, as is the custom in many North American tribes; moreover, the playing of games is limited to the boys. They do not use a ball in any of their games. Contests with bows and arrows are often held, also foot races and canoe races, the boys paddling the canoes instead of sailing them.

Five games were described and in them we find elements common to many primitive peoples. There is no singing while these games are in progress, and no mention was made of wagers on the result. The games are as follows:

1. Guessing who holds a small object. The boys sit in a row with hands behind them, facing the " guesser." A boy goes behind them and puts a small round stone in the hands of one boy, the guesser trying to determine who holds this round stone. Similar games are played by the North American Indians.

2. Running the gauntlet. One boy sits down and the other boys run by. The boy sitting down catches another boy, who also sits down facing him. The boys run between them and some are caught. A boy who is caught sits down next the boy who caught him. This is continued until all the boys are seated on the ground.

3. Blindfold. The boys stand in a circle, two boys in the middle of the circle being blindfolded. The children step forward and clap their hands behind the blindfolded boys who try to catch them. If a blindfolded boy catches one of the others he blindfolds the one he caught.

4. Circle game. Many boys join hands in a circle leaving one inside and one outside. The boy inside tries to get out, and the one who is outside tries to get in, the others trying to prevent this without loosing their hold on each other's hands.

5. " Playing ghost." About 10 boys join in this game, one taking the part of the doctor, another the " questioner," and two being the " ghosts." The term translated " ghost " is *ni'a,* which, according to the informants, is not used in any other connection. All the boys except the ghosts stand in two parallel lines facing each other, with the doctor and questioner opposite each other at one end. A little fire is burning halfway down one side, imitating the fire believed to keep harm from the musicians at a wedding. Pepper is put on this fire at a certain point in the game, imitating the " medicine " (cocoa bean) that is burned in front of the musicians. The boys who represent the ghosts have their faces painted red, black, and white in an outlandish manner, wear big hats and clothes much too large for them. The game opens with questions and answers by the two leaders.

Questioner: Who do you see coming?
Doctor: A ghost with one foot.
               (A ghost appears, hopping on one foot)
Questioner: Who do you see coming?
Doctor: A ghost walking funny.
               (The ghost walks in a grotesque manner)
Questioner: Who do you see coming?
Doctor: A ghost pounding on the ground with a stick.
        (The ghost pounds on the ground with his walking stick)
All the boys: Let's catch the ghost and tie him.

Pepper is then thrown on the fire and its fumes make the ghost " crazy." He waves his arms and struggles but the boys hold him, tie him with a rope, put him in a boat and cover him up. The ghost howls and wails. All the boys hide, and the second ghost comes to free his comrade. Together they try to find the boys who are hiding.

This game is usually played by moonlight with the older people looking on and laughing at the fun.